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**ASPECTS ECONOMIQUES DE L'UTILISATION
DES RESSOURCES HYDROELECTRIQUES**

Par Marcel MARY,
Contrôleur général
de l'Equipement à l'Electricité de France

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ASPECTS ECONOMIQUES DE L'UTILISATION DES
RESSOURCES HYDROELECTRIQUES

A.4.3.3.

par Marcel MARY Contrôleur Général de l'Equipe-
ment à Electricité de France

1 - Introduction

1-a) Le présent rapport a pour objet de résumer un certain nombre de considérations de nature à faciliter le choix des aménagements hydroélectriques à incorporer dans les Plans de développement et à orienter l'économiste dans la détermination des caractéristiques fondamentales de chacun de ces aménagements.

1-b) Ces réflexions sont le fruit d'une expérience de plusieurs années acquise par l'auteur à l'occasion de l'établissement de Plans Généraux d'Electrification demandés à Electricité de France par divers pays en voie de développement.

1-c) Le problème se présente de la manière suivante : Le prospecteur est supposé avoir déterminé, par un découpage judicieux du cours des rivières, établi de manière à permettre progressivement une utilisation rationnelle des puissances naturelles, un certain nombre de sites qui lui paraissent économiquement utilisables, c'est-à-dire qu'il a retenu des schémas comportant chacun l'emplacement du barrage et de la centrale. Il lui reste à déterminer la hauteur optima à donner au barrage et la puissance optima à donner à la centrale, à calculer la valeur économique des diverses variantes possibles, et à comparer les projets entre eux de manière à les inscrire dans le Plan de développement dans l'ordre le plus favorable à l'intérêt national.

1-d) Il serait naturellement souhaitable que la prospection complète du pays précédât ce choix, mais pratiquement ce désir est irréalisable, car dans la plupart des cas, les données topographiques, hydrologiques et géologiques sont insuffisantes. Il faut donc se contenter de comparer les projets les mieux connus, sous peine de retarder indéfiniment les décisions. L'attention des Gouvernements est, à cette occasion, attirée sur la nécessité de pousser activement la prospection pour accroître dans l'avenir le nombre des choix possibles.

2 - Valeur économique

2-a) Une centrale thermique est capable d'assurer, dans la limite de sa puissance installée, les fournitures en énergie d'un diagramme de charge de forme quelconque. Il est donc naturel de prendre comme terme de comparaison une telle centrale.

2-b) Une centrale hydroélectrique est limitée, non seulement par sa

puissance installée, mais également par le débit susceptible d'être turbiné à chaque instant. Elle est caractérisée par sa puissance garantie et par sa production annuelle moyenne.

2-c) La comparaison sera donc faite entre cette centrale et la puissance thermique équivalente sous ces deux aspects.

2-d) La méthode utilisée par Electricité de France et préconisée par l'auteur pour tous les pays consiste à calculer pour chacun des termes de comparaison le capital fictif qu'il serait théoriquement nécessaire de constituer à l'époque de la construction pour réaliser les ouvrages, les faire vivre et les renouveler indéfiniment. La comparaison de ces coûts fictifs totaux permet d'apprécier les valeurs économiques des projets et variantes étudiés.

2-e) Le calcul du taux de rentabilité, c'est-à-dire du revenu annuel de la différence des investissements entre hydraulique et thermique permet d'autre part de juger si les sommes investies dans l'hydraulique ont un rendement convenable par rapport aux investissements auxquels le pays pourrait procéder dans des branches d'activité autres que l'électricité, cette comparaison étant imposée par la limitation inévitable des sommes consacrées à l'ensemble de l'expansion économique.

3 - Mécanisme de l'interconnexion

3-a) Si l'on veut assurer le service d'un secteur à l'aide d'énergie hydroélectrique pure, il faut disposer de réservoirs saisonniers de grande capacité ou se résigner à n'utiliser qu'une fraction des eaux disponibles.

3-b) On en vient donc, dans la généralité des cas, à envisager des complexes interconnectés comprenant des centrales hydroélectriques et des centrales thermiques. Cette association présente des avantages considérables.

3-c) Dans le cas très fréquent où la centrale hydroélectrique peut concentrer sa production journalière sur un petit nombre d'heures, elle assure le service de pointe du réseau en période sèche, et le service de base en période humide. Le complément est assuré par la puissance thermique associée.

3-d) Il en résulte que, tout en disposant chaque jour de l'année, à l'heure de la pointe, de la totalité de la puissance installée (hydraulique plus thermique associée), les fournitures demandées à la centrale hydroélectrique peuvent varier d'un jour à l'autre dans des limites très importantes, et d'autant plus importantes que le pourcentage de puissance thermique associé est plus grand.

3-e) Pour avoir une vue claire de ces possibilités, il suffit de tracer un graphique comprenant deux courbes déduites de la courbe de charge journalière et représentant respectivement, en fonction du rapport $\frac{P_H}{P_H + P_T} = x$ les fractions, par rapport à l'énergie totale journalière demandée, de l'énergie de pointe et de l'énergie de base du diagramme de charge à desservir. Soient y_1 et y_2 ces

courbes. On trace aussi la courbe $\frac{Y_2}{Y_1}$.

3-f) Un tel graphique montre que, sous réserve d'associer à la puissance hydroélectrique une puissance thermique convenable, toute puissance hydroélectrique, aussi capricieuse que soit la rivière, est une puissance garantie. A titre d'exemple, si la puissance thermique est égale à la puissance hydroélectrique, le rapport des consommations extrêmes d'eau s'établit à la valeur de 3,5 pour un réseau ayant 5 000 heures d'utilisation.

3-g) On voit, à titre d'exemple, l'intérêt considérable que présente une telle coordination dans le cas d'une centrale située au pied d'un barrage de régularisation annuelle. Dans ce cas, le mot de régularisation n'a plus le sens étroit qu'on doit lui donner dans un régime hydraulique pur, c'est-à-dire l'obtention d'un débit journalier constant tout au long des années d'exploitation ; il a le sens d'une simple réduction de la variation des débits naturels compatible avec la grandeur de la puissance thermique associée. La capacité utilisée est alors fortement réduite. La hauteur du barrage peut être plus faible. Si la hauteur du barrage est donnée, la tranche d'eau utilisée est réduite et la puissance garantie de la centrale, qui est calculée sous la hauteur de chute minima, est augmentée.

3-h) L'analyse détaillée de ces mécanismes permet, par des raisonnements simples, de réduire d'une manière importante, le nombre des variantes que le projeteur sera amené à étudier dans chaque cas particulier en vue du calcul de la valeur économique des projets.

3-i) Les exemples qui suivent illustrent cette proposition, et montrent le cheminement des raisonnements.

4 - Détermination des caractéristiques d'un aménagement de haute chute

4-a) Le cas élémentaire étudié concerne la détermination des caractéristiques d'un aménagement hydroélectrique unique dans lequel la hauteur de chute est grande par rapport à la hauteur du barrage, et peut par conséquent être considérée comme constante. La puissance est proportionnelle au débit.

4-b) Cet aménagement est supposé devoir être dimensionné de manière à assurer en association avec une puissance thermique convenablement calculée, le service d'un diagramme de charge de même forme que le diagramme de charge de l'ensemble du réseau, la puissance totale de l'ensemble associé étant utilisée à l'heure de la pointe.

4-c) Une recherche sans idée directrice consisterait à faire varier les trois grandeurs à préciser : hauteur du barrage, puissance à installer, puissance thermique à associer et à calculer dans chaque cas la valeur économique en vue de la recherche de l'optimum.

4-d) L'analyse du fonctionnement en régime interconnecté montre que ces trois paramètres se réduisent à un seul pour toutes les solutions dans lesquelles on cherche à utiliser l'eau au maximum, sans pertes notables par déversements.

4-e) Pour une hauteur donnée du barrage, prise comme paramètre unique, c'est-à-dire pour une courbe donnée de capacité, on peut aisément déterminer par un examen des courbes des débits, le débit minimum journalier Q_m sur lequel on peut compter en ajoutant au débit d'étiage la vidange du réservoir et la valeur Q_m du débit qu'il y a lieu d'utiliser en hautes eaux pour éviter les déversements compte tenu des quantités d'eau à réserver pour le remplissage de la réserve.

4-f) Le rapport $\frac{Q_m}{Q_H}$ est une mesure de l'irrégularité de la rivière compte tenu du jeu du réservoir. Le graphique cité en 3-e) donne par lecture directe la valeur du rapport $\frac{P_H}{P_F + T}$ correspondant à cette irrégularité d'où $\frac{P_T}{P_H}$, proportion de puissance thermique à associer.

4-f)i) La proportion de thermique associé dépend donc uniquement de la hauteur du barrage.

4-g) En écrivant d'autre part que la quantité d'eau dont on dispose en étiage correspond à celle qui est nécessaire pour satisfaire les fournitures de pointe, et en hautes eaux pour satisfaire les fourniture de base, on en déduit la valeur Q du débit à équiper.

4-g)i) Sans entrer dans le détail des démonstrations, on trouve les relations suivantes, pour un réseau de 5 000 heures :

$$\frac{Q}{Q_m} = 1,75 \frac{x}{y_1} \quad \frac{Q}{Q_m} = 1,75 \frac{x}{y_2} \quad (1,75 = \frac{8\,760}{5\,000})$$

4-g)ii) Il se trouve que la valeur de Q est pratiquement indépendante de la hauteur du barrage et égale à 1,75 fois le module. Ceci provient du fait que la centrale, qui fonctionne un nombre d'heures variable suivant les époques de l'année, a, de toutes manières, au total, un nombre d'heures de fonctionnement sensiblement égal à l'utilisation du réseau.

4-g)iii) La puissance de la centrale hydroélectrique est donc déterminée, et la grandeur de la puissance thermique à associer est une fonction directe de la hauteur du barrage.

4-h) La méthode d'approche est donc extrêmement simple : En faisant trois ou quatre hypothèses pour la hauteur du barrage, on déterminera pour chacune d'elles toutes les caractéristiques d'un complexe élémentaire hydraulique-thermique assurant le service d'un diagramme de charge semblable à celui du réseau et dans lequel la totalité de la puissance installée est une puissance garantie.

4 h)i) Il suffira de calculer les valeurs économiques de ces trois ou quatre complexes pour choisir le meilleur.

4-i) Il se peut que la puissance thermique existe déjà sur le réseau ou au contraire qu'il soit nécessaire de la créer. Dans le premier cas, les frais de premier établissement de la puissance thermique ne sont pas à prendre en compte dans le calcul économique, mais uniquement ses frais de fonctionnement et de renouvellement.

5 - Développement des raisonnements

5-a) Sans entrer dans le détail des démonstrations, on indiquera ci-après, à titre d'exemples, un certain nombre de propositions

déduites des considérations qui précèdent.

5-b) 1^e Proposition Il peut arriver que la solution étudiée ci-dessus conduise à un barrage de taille excessive, incompatible avec les données topographiques locales, ou à une proportion de puissance thermique trop importante. On recherchera alors des solutions n'utilisant l'eau que partiellement. Les calculs sont conduits de la même manière, en diminuant simplement la valeur de Q_M . Mais dans ce cas la valeur de Q n'est plus une constante, car le nombre d'heures de fonctionnement annuel augmente lorsque Q_M diminue.

5-c) 2^e Proposition Le réseau n'est pas alimenté par une seule centrale hydroélectrique, mais par un nombre plus ou moins important de centrales. L'étude combinée de cet ensemble se présente différemment suivant que les régimes des rivières sont concordants (étiages simultanés et hautes eaux simultanées) ou au contraire discordants. Le premier cas est fréquent dans les pays tropicaux, exception faite des interventions provoquées par les barrages d'irrigation.

5-c)i) Dans le cas de régimes concordants, le réseau sera constitué par la juxtaposition de complexes élémentaires hydraulique-thermique tels que celui qui a été défini au § 4. La puissance thermique nécessaire pour régulariser l'ensemble s'obtient par addition des puissances thermiques calculées pour chacun des complexes élémentaires.

5-c)ii) Dans le cas de régimes discordants, on calculera la puissance thermique nécessaire pour compenser les irrégularités de l'ensemble de la production hydraulique avant et après introduction de la centrale nouvelle. Par différence, on aura la puissance thermique à associer à cette nouvelle centrale.

5-d) 3^e Proposition Lorsque la hauteur de chute est variable (centrale de pied de barrage) le nombre de cas à examiner augmente, car un paramètre nouveau s'est introduit. La puissance garantie correspond en effet au niveau minimum du plan d'eau du lac. Mais les principes du calcul restent les mêmes.

5-e) 4^e Proposition Un Plan s'établit à partir d'une situation existante. La première recherche à effectuer consistera à déterminer si le réseau est constitué de telle sorte que la proportion de puissance thermique correspond à ce qui est nécessaire et suffisant pour que la totalité de la puissance hydraulique soit garantie, ou au contraire, si elle est insuffisante ou surabondante.

5-e)i) On examinera ensuite s'il est rentable de rétablir l'équilibre par la construction de centrales hydroélectriques ou l'introduction de puissance thermique. De toutes manières, l'introduction d'une centrale supplémentaire s'accompagnera du calcul de la puissance garantie nouvelle et le gain sera porté au crédit de cette réalisation, dans l'ordre historique. La valeur économique de chaque aménagement dépend donc de l'ordre des réalisations.

5-e)ii) Dans tout ce qui précède, il n'a été question que des centrales d'éclusées ou de lac. L'ensemble des centrales au fil de l'eau sera compté pour sa puissance garantie en étiage et porté en base de diagramme ; les autres calculs seront effectués sur le diagramme ainsi amputé par sa base.

5-f) 5^e Proposition Un suréquipement par rapport à la valeur $Q =$

1,75 M n'est généralement rentable que s'il y a surabondance de puissance thermique par rapport à l'optimum défini au § 4. Il n'a pas de raison d'être si le réseau est constamment maintenu dans un bon équilibre hydraulique-thermique.

5-g) 6^e Proposition Les calculs devront être effectués en tenant compte des variations dans l'avenir du nombre d'heures d'utilisation du réseau, car la proportion de thermique augmente avec ce nombre d'heures.

5-h) 7^e Proposition Contrairement à une opinion fréquemment émise, il n'y a pas d'incompatibilité entre l'utilisation d'un réservoir pour l'irrigation et son utilisation énergétique, comportant la garantie de puissance de la centrale de pied. Il y a seulement nécessité d'un arbitrage, le plan d'eau ne devant jamais descendre trop bas et le débit d'ailleurs faible nécessaire au service de pointe devant être turbiné à l'époque où l'irrigant n'a pas besoin d'eau. Dans la plupart des cas, la lenteur de la progression des périmètres irrigués donne d'ailleurs une liberté complète à l'électricien pendant de nombreuses années.

5-i) Les applications de la méthode proposée peuvent être étendues à de très nombreux cas. Les propositions émises ci-dessus ne sont que des exemples de la fertilité de cette méthode.

6 - Conclusion

6-a) Les considérations de la présente note n'ont pas la prétention de résoudre automatiquement les problèmes posés par l'établissement d'un Plan de développement de l'électricité, mais elles peuvent être d'une grande utilité, dans leur simplicité, pour les économistes chargés de se pencher sur ces questions.

6-b) L'essentiel de la méthode consiste à associer à chaque aménagement hydroélectrique nouveau une puissance thermique convenable de telle sorte que, à chaque étape du Plan, la totalité de la puissance installée soit nécessaire et suffisante à l'heure de la pointe (à l'exception naturellement des puissances tenues en réserve pour l'entretien et les incidents et à l'exception de la puissance des centrales au fil de l'eau).

6-c) Le manque de fonds disponibles peut amener à construire des centrales thermiques plus rapidement que ne le nécessiterait le programme le plus favorable à long terme. Mais ces puissances thermiques excédentaires seront utilisées avec profit dans les phases ultérieures de l'aménagement hydroélectrique.



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MODERN TECHNIQUES
APPLICABLE TO THE DESIGN
AND CONSTRUCTION OF STRUCTURES
FOR SURFACE WATER
USING LOCAL MATERIALS AND LABOUR

By Shri C. L. HANDA, I. S. E.,
Member Designs and Research,
Central Water and Power Commission

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

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MODERN TECHNIQUES APPLICABLE TO THE DESIGN
AND CONSTRUCTION OF STRUCTURES FOR SURFACE
WATER USING LOCAL MATERIALS AND LABOUR
BY

Shri C.L.Handa, I.S.E.,
Member (Designs and Research)
Central Water and Power Commission.

INTRODUCTION

1. India has a gross geographical area of about 811 million acres. The average annual rainfall is below 50 inches and in most parts this rainfall is concentrated in four months from June to September. As a result, all the surface water tends to run off into the sea in the form of floods. Under these conditions, the most economical and effective method of utilising surface water is by constructing river structures for storage and diversion. Such structures have been constructed in India from ancient times. The Grand Anicut across Cauvery River in Tanjore(S. India) built some time in the 10th century is an outstanding example.

2. The total annual flow of all the rivers in India is estimated to be about 1350 million acre feet, of which about 430 million acre feet is considered economically utilisable for beneficial use. The corresponding potential for hydro-power development is about 41 million kilowatts. Out of these resources, the actual utilisation upto a decade ago was only 76 million acre feet of water for irrigation and an installed hydro-power capacity of 0.5 million kilowatts. The exploding population and the relative backwardness of the country called for a rapid development of its available resources. A series of five year plans for the organised and rapid development was embarked upon in 1950-51. By a judicious utilisation of modern developments in design and construction techniques adapted to the availability of men, materials and construction equipment, we have been able, by the end of 1961 to utilise an additional 36 million acre feet of water for irrigation and install an additional power capacity of 1.4 million kilowatts. The most important techniques and features which have been made use of are described in the following paragraphs.

WEIRS AND BARRAGES

3. Weirs are about the cheapest methods for diversion of river waters. Major weirs were constructed during the end of the

last century. The weirs across the Sutlej, Ravi, Ganga, Jumna, Cauvery, Krishna, Godavari and Mahanadi are outstanding examples. However, these have the disadvantage of obstructing the waterway, which particularly affects the regime of alluvial rivers. In such cases, a gated weir popularly known as barrage with the sill of the weir almost at river bed is now preferred. The advantage is that high enough pond levels are possible with limited afflux and less interference with the natural regime of the river. Outstanding examples of this type of construction are Kosi Barrage (3760 ft. long), Nangal Barrage (2700 ft. long) and Durgapur Barrage (2270 ft. long). The salient technical improvements in the modern weirs and barrages are the use of reinforced concrete floors (to reduce thickness and consequent dewatering), improved profiles based on hydraulic models to increase discharge coefficient and stabilise the jump, provision of sheetpile cutoffs and relief wells, and reverse filters for protection against piping, and use of comprehensive hydraulic models to evolve and test designs.

4. An associated problem with water diversion by barrage structures is the exclusion of excessive sediment from the water so diverted. In addition to adopting the conventional methods of utilising flow curvature and providing stilling pockets with undersluices and divide walls, extensive use is now made of silt excluder tunnels and sand extractors or ejectors. The design of these excluder and ejectors are decided on the basis of hydraulic model experiments to suit individual cases.

5. The use of hydraulic models with mobile beds and vertically exaggerated scales is another technique being used for the study of river structures. The interpretation of the model behaviour has to be done carefully keeping in view the inability of model to adjust to variable conditions, the effect of rigid structures on exaggerated vertical scale etc. The improvements in design envisaged on the models have been largely substantiated, and realized in the prototype structures which have been constructed. The technique has become a powerful and in fact an indispensable tool in the designs of river structures.

DAMS

6. Though the construction of major dams in India commenced in the 17th century (Periyar 176 feet high), (Khadakwasla 130 ft.), the largest dam existing prior to the commencement of the five year plans was Mettur with height of 231 feet and having a capacity of 2 million acre feet. Since then some large dams have been completed or are under construction. Bhakra (740 ft. high, 7.4 m.a.ft. capacity), Nagarjuna-sagar (370 ft., 9.3 m.a.ft.) Rihand (296 ft., 8.6 m.a.ft. capacity), Gandhisagar (212 ft. 6.85 m.a.ft.) and Hirakud (200 ft., 6.6 m.a.ft.) are some outstanding examples.

7. Where concrete has been used for major dams, modern construction methods have been followed. Concreting rates upto 5000 cu.yds. per day have been attained in some cases. This

has been made possible by the appropriate use of belt conveyors, automatic batching plants, trestles and cranes or cableways. The 3050 ft. long 20 ton cableway used at Rihand for concrete placement is particularly worth mentioning. Natural aggregates suitable for concrete construction were available only in one or two of these dams. In an extreme case like Rihand, the entire aggregate and even most of the sand had to be processed for quarried rock.

8. Mass concrete placed at a rapid rate brings in the problem of temperature control to avoid high temperature stresses and consequent cracking of the dam. Precooling of the aggregates and postcooling of the placed concrete have been used individually or in conjunction according to actual requirements. Precooling was resorted to in Vaitarna, Rihand and Koyna dams while both pre and post cooling was used in the 740 ft. high Bhakra Dam.

9. Another means of controlling temperature is the reduction of the cement content in concrete. 15% to 25% reduction of cement content has been achieved by the admixture of indigenously manufactured pozollanas. Burnt brick powder, calcined shales and fly ash are some of the pozollanas successfully used. Advantage has also been taken of the favourable effect of adding air entraining agents.

10. The practice of providing plan transverse contraction joints at regular intervals is normally followed. However, shear keys and arrangement for grouting such joints have been made at Bhakra Dam so that a certain portion of load is transferred to the abutment by twist and horizontal bending action.

11. Rubble masonry has been preferred to concrete at many sites. Rubble masonry construction employs a large labour force with a high proportion of unskilled workmen and requires less mechanisation and is, therefore, suited to local conditions. This has led to its adoption wherever it is consistent with the required rate of progress, which in turn depends on working space. However, some diffidence about its use on high dams existed, as no strength tests had been conducted on masonry. The mortar strength used to be taken as the limiting strength of masonry. Since the individual stones are large, testing machines of the capacity required for testing the large size specimens of masonry were not available. A compression testing rig of four and a half million pounds capacity was improvised at Hirakud Laboratory. The equipment was set up in a niche in a quarry face. The force in this test was provided by four 500 ton hydraulic jacks reacting against the roof and floor of the niche. Test results showed that rubble masonry in 1:3 concrete mortar can give crushing strengths of the order of 2500 to 3000 lbs. in 28 days. These tests have made it possible to use rubble masonry for the 370 ft. high Nagarjunaagar dam, of which the lower portions were originally specified to be done in concrete.

12. When rubble masonry is used for higher dams it is necessary to use labour and mechanisation in a judicious combination. In this case the transport of stones and mortar have to be mechanised especially at higher elevations. Trestles, rail cars, cranes, monotowers have been used for this purpose.

13. The spillway and energy dissipating devices are invariably tested on hydraulic models. Large size sluices are also used in addition to overfall spillways for discharging the floods and also as outlets for released. Sizes upto 12 feet by 22 feet operating under heads 100 feet and more have been used. The design of such sluices have been based on extensive hydraulic model experiments.

14. Photoelastic methods have been employed to determine stresses in concrete and masonry structures. Reinforcements around large size openings, treatment of weak foundation strata, and stresses in spillway training walls are some of the problems solved by this method. The conclusions have often been confirmed by solution of stress functions by relaxation methods.

15. In the field of earth dam construction, organised heavy earth moving equipment is generally employed. Good quality control and rapid rates of progress have been achieved, for example, at Hirakud Dam involving a volume of 24 million cubic yards of earth work. In order to achieve efficient and economic use of the equipment, regional training centres for earth-moving equipment operators, mechanics and foremen have been established.

16. Foundation treatments for concrete and masonry dams on rocks conform to accepted practices namely, consolidation grouting and a fairly deep impervious grout curtain. In earth dams, on other than rock foundations, a positive cutoff into impervious strata is preferred, usually by means of cutoff trenches. Where excavation for deep cutoffs has not been possible, due to high permeability and consequent dewatering problems, clay, cement or chemical grouting is now resorted to. A recent example is at Kotah earth dam where a grout curtain upto 60 feet depth has been constructed in a foundation consisting of sand and boulders with some lenses of clay. Clay, cement and sodium silicate were mixed in varying proportions for the grout.

HYDRO ELECTRIC POWER STATIONS

17. In a country where fuel resources are concentrated in a few regions, and further restricted by inadequate transport facilities hydropower generally becomes the cheapest source of power. Moreover, a relatively large portion of cost of generation can be met from indigenous materials and labour. Many of First and Second Five Year Plan Projects were conceived as multipurpose projects and considerable power generation at the dams was envisaged. Though some limitation to this type of development is inevitable due to the seasonal pattern of releases of water for irrigation, co-ordinated operation on grid with other power stations, having storages not tied up with irrigation patterns is resorted to.

18. The modern trend towards the use of largest sized machines consistent with efficient operation of stations in a growing load pattern and transport facilities available, is followed. Thus at Bhakra, 90,000 KW units have been installed

for the Left Bank Power House, and 120,000 KW units are being obtained for the Right Bank Power House. Ultimate installed capacities are designed with a view to future peaking operation that may be necessary for co-ordination with thermal and nuclear stations which have also been envisaged. Underground power stations have been adopted when they proved more economical on the basis of penstock cost, capitalised annual charges or increased power for the same or less cost. Koyna (240,000 KW), Maithon (60,000 KW) are such examples. Where the use of mild steel for penstocks resulted in excessive thickness, high tensile steel has been used instead. The Power House designs follow conventional methods.

19. Excavation below ground water level in pervious foundations has been done by the well point system of dewatering. Depths upto 60 feet below ground water level have been excavated by this method. Excavation problems are further reduced by the introduction of tubular turbines which are being considered for some of the recent projects. The use of tubular turbines will result in economy in the cost of power house structure as well.

CANALS

20. In canal work, the excavation is semi-mechanised. Generally heavy excavating equipment like draglines, etc. have been adopted in main canal excavation, but the branches and field channels are still largely hand excavated. Lining construction and design is largely influenced by availability of materials, labour etc. locally. Thus brick and tiles have been used where materials for concrete or the requisite machinery are not readily available. The biggest single use of tile lining is in the Rajasthan Canal having a head discharge of 20,000 cusecs and a length of 425 miles.

PRESTRESSED CONCRETE

21. Prestressed concrete will be increasingly used in the field of surface water utilisation. Examples of the utilisation are the strengthening of Tansa Dam in Bombay by means of prestressed cables anchored into the foundation rock, the Kunu Syphon, where 20 feet diameter prestressed concrete syphon pipe, 6000 feet long under a hydrostatic pressure of 85 feet carries canal waters across Kunu river.

INVESTIGATIONS

22. One of the greatest retarding factors in the rapid construction of structures for surface water utilisation is lack of surveys, topographical and hydrographic. To mitigate the delays due to this factor, Reservoir Surveys are now done with the help of aerial photography. Automatic rainfall recording stations are now used at inaccessible locations. Automatic water level recorders, and even radio operated water level gauges have been employed. In the field of instrumentation continuous research is being conducted for improving techniques for making hydraulic measurements. As an illustration, the big flood

discharge of Mutha river was gauged by the Central Water and Power Commission in collaboration with Atomic Energy Commission by use of Radio Isotopes and some promising results obtained. Radio Isotopes have also been used as tracers for sediment movements. In this field the techniques of Fluorescent tracer has great scope since the hazards connected with radio isotopes are avoided and also because of the difficulty of obtaining radio isotopes in underdeveloped countries.

ORGANISATION

23. The planning for utilisation of surface water has to be done in a basinwise or preferably on a regionwise basis for maximum benefit. Recognising this, the Central Water and Power Commission is responsible for initiating, co-ordinating and furthering river valley projects in the country. The constitution makes the Central Government responsible for proper regulation and development of interstate rivers and river valleys to the extent considered by Parliament, to be necessary in the Public interest. In conformity with the above responsibility, two Acts namely, Inter-state Dispute Act, 1956 and River Board Act 1956, have been passed. The first provides for adjudication of disputes relating to utilisation of interstate rivers and river valleys and the second for regulation and development of inter-state rivers and their valleys. Projects falling entirely within a State are being planned and constructed by the concerned State itself.

24. In the field of research, the activities of various hydraulic research institutions are co-ordinated by the Central Board of Irrigation and Power, so that there is no duplication of research programmes.

25. The Library and Information Bureau of the Central Water and Power Commission renders valuable service by providing a comprehensive collection of books and through its technical abstracts.

OUTLOOK FOR THE FUTURE

26. The experience and momentum gained in the first two five year plans are being put to beneficial use in implementing the third and fourth plan projects. It is hoped that the major and medium projects alone will provide irrigation facilities to an additional 46 million acres by the end of the fourth plan, as compared to the 22 million acres of the pre-plan period. The corresponding increase in the installed capacity for hydro-power generation will be about 11 million kilowatts. This would amount only to about 25% exploitation of the available hydro potential and there will still be plenty of scope for further development.



UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
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Agenda Item: A.3.3

South Africa

GROUND-WATER PROSPECTING METHODS
USED IN THE REPUBLIC OF SOUTH AFRICA

By L.E. KENT, Ph.D., F.R.S.S.Af., F.G.S.
Assistant Director,
Geological Survey of South Africa
and J.F. ENSLIN, D.Sc.,
Principal Hydrologist,
Division of Hydrological Research

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

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GROUND-WATER PROSPECTING METHODS USED IN THE REPUBLIC OF SOUTH AFRICA

A.3.3. L.E. Kent, Ph.D., F.R.S.S.Af., F.G.S.
Assistant Director, Geological Survey of South Africa
and J.P. Enslin, D.Sc.,
Principal Hydrologist, Division of Hydrological Research,
Department of Water Affairs, South Africa,
formerly Chief Geologist, Geological Survey

1. Introduction

(a) The utilization of the semi-arid and arid 65% of the Republic of South Africa depends very largely on development of underground water and, even in the relatively well-watered parts, supplementary underground supplies are usually essential for efficient farming.

(b) Thick deposits of sand and gravel, and permeable sandstone, the principal aquifers in countries such as the U.S.A., are scarce in South Africa and most of the c.500,000 bore-holes are in bedrock. With the exception of some sandstone, the rocks have virtually no inherent permeability; the aquifers are secondary in origin and have formed by fracturing, weathering and solution. They are often narrow zones which are difficult to locate under soil cover. The percentage of weak and dry bore-holes is thus very high:

<u>Percentage of bore-holes</u>	<u>Initial yield exceeded</u>
2	5000 imp.g./hr (22.5 cu.m./hr)
11	2000 " " { 9.0 " " }
21	1000 " " { 4.5 " " }
31	500 " " { 2.25 " " }
42	200 " " { 0.9 " " }
50	100 " " { 0.45 " " }

As the vast majority of the holes are drilled for stock watering and for domestic purposes on farms, a successful bore-hole is generally taken as one with a yield exceeding 100 g. (0.45 cu.m.)/hr.

(c) Water-divining has been, and still is to some extent, used for locating drilling sites - usually with very disappointing results. Scientific methods developed by the Geological Survey for South African conditions have proved valuable in considerably reducing the number of failures and the costs of developing usable supplies. Savings of up to 50% have been effected (2,7,9,11).

2. Preliminary Studies of Geohydrological Data

Logs of the c.85,000 bore-holes drilled by government drills and files of water analyses provide useful indications as to the nature of the aquifers, depth to water, and quantity and quality to be expected (8)

3. Indications from Vegetation

(a) Dykes, which are often flanked by water-bearing zones, are generally marked by lines of trees and more luxuriant bushes (par.5.b.(1)), so also are some crush-zones and major joints.

(b) On the Transvaal highveld a grass (Fingerhuthia sealeriae-formis) seems to flourish only where the underlying rocks are permeable and the water-table is very near the surface. Using it as an indicator, successful bore-holes have been drilled in sedimentary rocks within short distances of failures. It is believed that the very shallow water-table required by this grass is maintained by ground-water flow from higher-lying areas.

(c) The Karroo amygdaloidal basalt in the central Transvaal tends to weather to only shallow depths. Locally it is cut by vertical fissure-zones that are generally hidden by soil. During the dry winter months the soil dries out, and before the first rains very little water is available to the indigenous plants, save deep-rooted ones situated over fissure-zones that form aquifers. In early spring, lines of green trees demarcate these aquifers and very successful boring sites have been selected.

4. Geological Surveys

(a) Geological reconnaissance, using air photographs which cover almost the entire country, is useful for tracing dykes, zones of fracturing and other favourable structures. In the field, the topography is noted in relation to the disposition of the rocks and their dips, if layered, to obtain an idea whether recharge of aquifers is likely under the local conditions of climate, soil and vegetation. In some cases it is possible to deduce the hydrological properties of some rocks at depth and select sites (8). Examples follow:

(i) In parts of Zululand, the Karroo basalt is cut by dykes of volcanic breccia that form conspicuous bushy ridges. About 60% of the bore-holes drilled in or next to these dykes proved successful as compared with 28% success on non-geological/geophysical sites (11).

(ii) If the contacts of Karroo dolerite dykes cutting sedimentary rocks are well exposed, drilling sites may be selected so as to penetrate the contact-zones below the water-table (par.5.b.). Some of the narrow dykes are themselves extensively fractured and very successful bore-holes have been drilled in them (9).

(iii) Fault-zones have been found in cliffs and cuttings and projected to soil-covered areas where sites were required. Some have yielded fairly large supplies.

(b) The geohydrological section, Fig.I, was prepared by geological mapping and plotting the logs of a row of experimental bore-holes. Five aquifers, representative of some of the more important types in the country, were delineated. Nos.1 and 4 are formed by weathered diabase and are relatively shallow (par.5.c.(iv)); Nos.2 and 3 are shales that have acquired fairly high permeabilities through jointing and cleavage and extend much deeper. No.5 is the fracture-zone of a vertical fault; it is recharged by rain falling on the bare quartzite face of the ridge immediately to the south and also by influent seepage from a river further east. The underground water overflows from No.5 into No.4 and from there into the one with the largest storage, No.3, which has been fully developed for spray irrigation. No.2 is recharged by seepage from the adjoining aquicludes at about 9 cu.m./hr. Such experimental drilling facilitates the selection of successful boring sites.

5. Geophysical Surveys

(a) Geophysical surveys, using sometimes more than one method, often have to be employed to supplement geological ones and are essential when the potential aquifers are hidden by soil or alluvium.

(b) Surveys of the vertical magnetic field have proved valuable for tracing dykes and the margins of intrusive sheets.

(i) The generally almost flat-lying sandstone, mudstone and shale of the Karroo System (Carboniferous to Triassic), which covers nearly half the country, usually have very low permeabilities and specific yields. On some farms over a hundred bore-holes have been drilled in them without striking more than a few gallons per hour. It was found that narrow, indurated zones of intense jointing along the margins of many of the numerous dolerite intrusions form aquifers that are recharged by percolation from adjacent aquicludes.

(ii) The dolerite dykes are generally 5 to 10 m. wide and the indurated contact-zones seldom exceed 0.5 m. Bore-holes must thus be sited with great precision to strike such narrow aquifers at optimum depths. Fortunately most of the dykes are magnetic and a technique of interpretation of their magnetic anomalies has been developed to locate their margins accurately even under deep soil cover (4). Fig. II is a typical example. Eighteen bore-holes had been drilled near the homestead on this farm, but all were failures. A long magnetometric traverse revealed the presence of a dyke which was traced by a series of short traverses. Both positive and negative peaks occur, which mark the contacts of the hidden dyke. Under deep soil a dyke generally gives rise to only a single, rather wide anomaly due to superposition of anomalies from individual poles; however, if sufficient traverses are made, some will show anomalies with two or more peaks (6). The two parallel lines joining the outer peaks approximate within a metre to the contacts of the dyke. On the farm in question the indurated zone was first just missed; the machine was moved 1 m. nearer the contact - a supply of 1800 g. (8.2 cu.m.)/hr was then obtained.

(iii) Unfortunately it has not proved possible to determine the dips of the dykes from their magnetic anomalies, which are almost entirely due to remanent magnetization (4). Dip indications may be obtained from their traces if they cross valleys, and from logs of existing bore-holes. Usually it is necessary to drill trial holes to establish the attitudes of a dyke so that bore-holes may be sited to strike one or other of the contact-zones below the water-table. Near-surface tilting of some dykes has caused difficulties (4).

(iv) In areas underlain by dolerite sheets, the water is generally found in the upper and/or lower contact-zones, if not too deeply buried. The lower is usually the better aquifer, especially fairly near the denuded edges of the intrusions (9). In general, conditions are favourable where the contact-zones dip and are unfavourable where they are horizontal.

(c) Electrical resistivity surveys are mainly used for locating basins and closed troughs of weathering in igneous rocks, which cover almost a third of the country (6).

(i) It has been found that it is much faster to use an alternating current or reversed direct current, with steel electrodes, than direct current with non-polarising electrodes. The Wenner configuration (4 electrodes equally spaced in a straight line) is usually used, with a 5-man crew. Due to the difficulty of getting current into dry

ground, it is often necessary to drive the electrodes to depths of a metre or more. Their extraction is often difficult and time-wasting. A combined electrode and hammer was thus recently developed. It consists of a steel electrode $1\frac{1}{2}$ m. long with a collar at its upper end. A tubular hammer is fitted and a sleeve welded on to the inside of its lower end to prevent the electrode falling out. It is easily driven by downward strokes of the hammer and is readily extracted by a few upward jars.

(ii) Depth-probe traverses are generally resorted to. To avoid excessive lateral effects, the electrode spreads are orientated, if possible, parallel to the strike of layered rocks and dykes. The depths to the contact between weathered and solid rock are empirically determined in the field from apparent resistivity/electrode separation curves (3,6). When deep weathering is found, the traverse is expanded into a grid. Resistivity sections are drawn through the depth-probe centres and lateral effects eliminated (3). A geohydrological interpretation is then made.

(iii) Fig.III shows part of a farm on Bushveld granite where a basin of weathering, with a maximum depth of 35 m., was found. Note that the subcontours of the basin are not related to the surface contours. This is nearly always the case; in some granitic areas the deepest weathering is on broad ridges between water-courses, and boring sites are much more successful there than in the valleys.

(iv) In basins and troughs of weathering, the main supplies of water are generally struck in the irregular partially weathered and broken zone just below the weathered rock. For this reason drilling should continue to a depth of as much as 15 m. below the depth of weathering deduced from depth-probes (2). A "broken" zone is essential for successful bore-holes in basic igneous rocks, which weather to clayey materials with very low permeabilities. Unfortunately its presence cannot be established by electrical resistivity surveys and failures have been proved, by electric logging, to be due to its absence in basins or sections of basins. The yield of a bore-hole is affected by the slope of the floor of the basin as steeper pressure gradients can develop under pumping in thin, dipping aquifers than in horizontal ones (3,6).

(v) The electrical resistivity method is also used to determine the thickness of sedimentary rocks overlying dolerite sheets (par.5.b. (iv)) and to trace old river channels filled with water-bearing sands and gravels. Resistivity logging is extensively used to determine the actual depths, thicknesses and resistivities of aquifers and, for bore-holes in progress, to indicate whether deepening is justified. Such logging eliminates much fruitless drilling.

(d) The electromagnetic method is used for locating fissures under soil cover in rocks that are not weathered sufficiently deeply to form basins, and in which fractures are not associated with magnetic dykes and also do not show on air photographs. The method fails, however, if the conductivity of the fissured zone is the same as the country-rock.

(i) An alternating current of audio-frequency is introduced conductively into the ground (1). Measurements of the tangential component of the horizontal electromagnetic field are taken on concentric circles around the current source. Peaks indicate current concentrations due to narrow conducting zones which are generally water-filled. If such peaks are obtained on the circles, they are further traced by

measurements on short arcs (5). In open country 20 hectares can be covered per day by a 6-man crew. Supplies of up to 50 cu.m./hr have been obtained.

(ii) The example (Fig.IV) is a site on Archaean granite. A prominent quartz vein had been used for siting a bore-hole (No.1), but only a small supply was struck and the second bore-hole away from the vein was dry. An electromagnetic survey disclosed an inclined fracture-zone up to 60 m. from the quartz vein. Sites selected to strike it at optimum depths gave satisfactory yields. The fissure-zone apparently branches off from the quartz vein, which is for the most part impermeable. In the case of such inclined zones, the electromagnetic peaks are displaced from the sub-outcrop in the direction of dip. In general the depth below a peak to the fissure is about twice the thickness of the overburden (5).

(e) Seismic and gravity surveys have been used recently with success to determine the configuration of an artesian basin.

The Geological Survey's draughtsmen are thanked for preparing the figures.

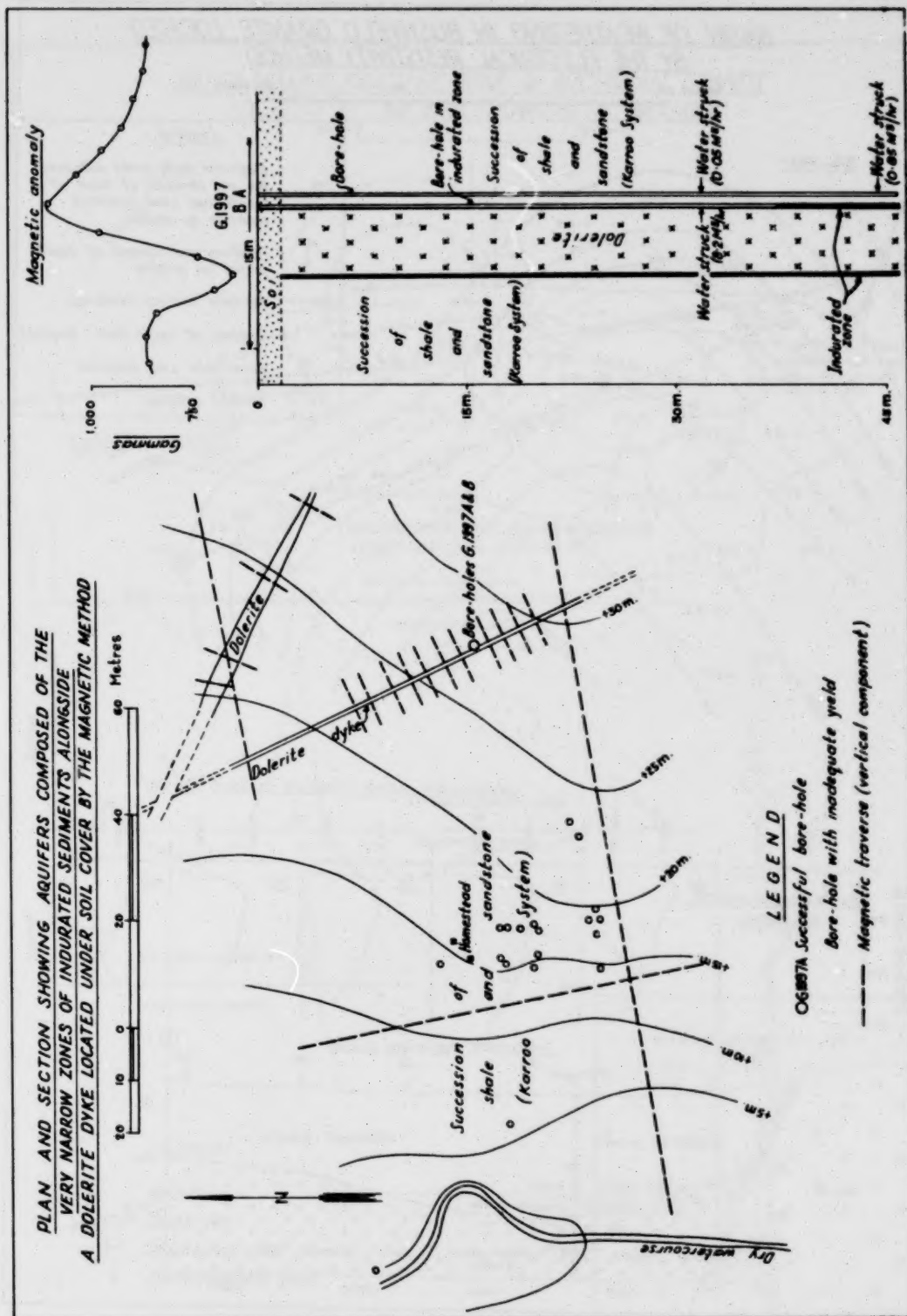
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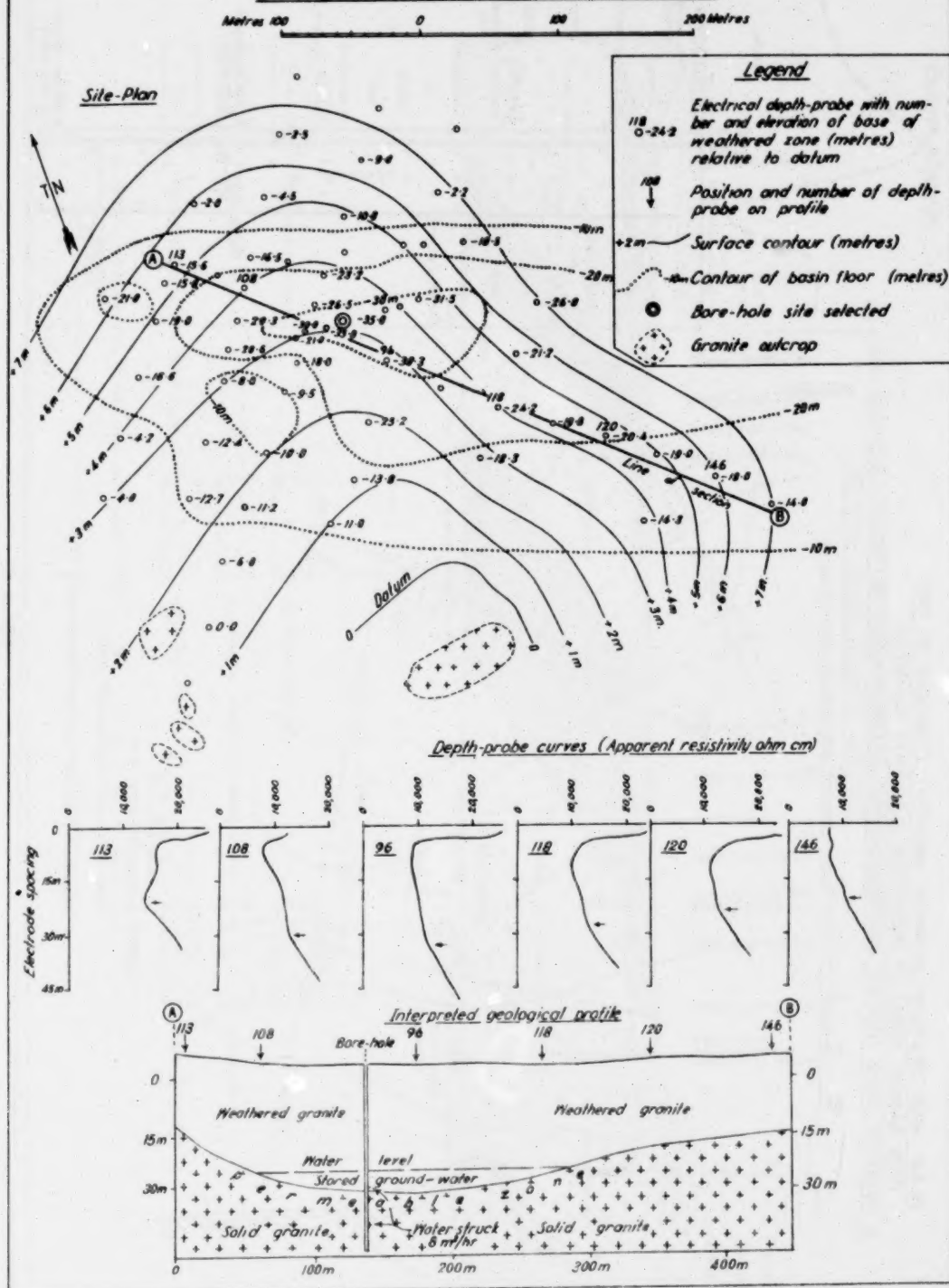
Horizontal scale = Method scale

Figure 1

PLAN AND SECTION SHOWING AQUIFERS COMPOSED OF THE
VERY NARROW ZONES OF INDURATED SEDIMENTS ALONGSIDE
A DOLERITE DYKE LOCATED UNDER SOIL COVER BY THE MAGNETIC METHOD



BASIN OF WEATHERING IN BUSHVELD GRANITE LOCATED BY THE ELECTRICAL RESISTIVITY METHOD



WATER-BEARING FRACTURE-ZONE IN ARCHAEOAN GRANITE LOCATED BY AN ELECTROMAGNETIC METHOD

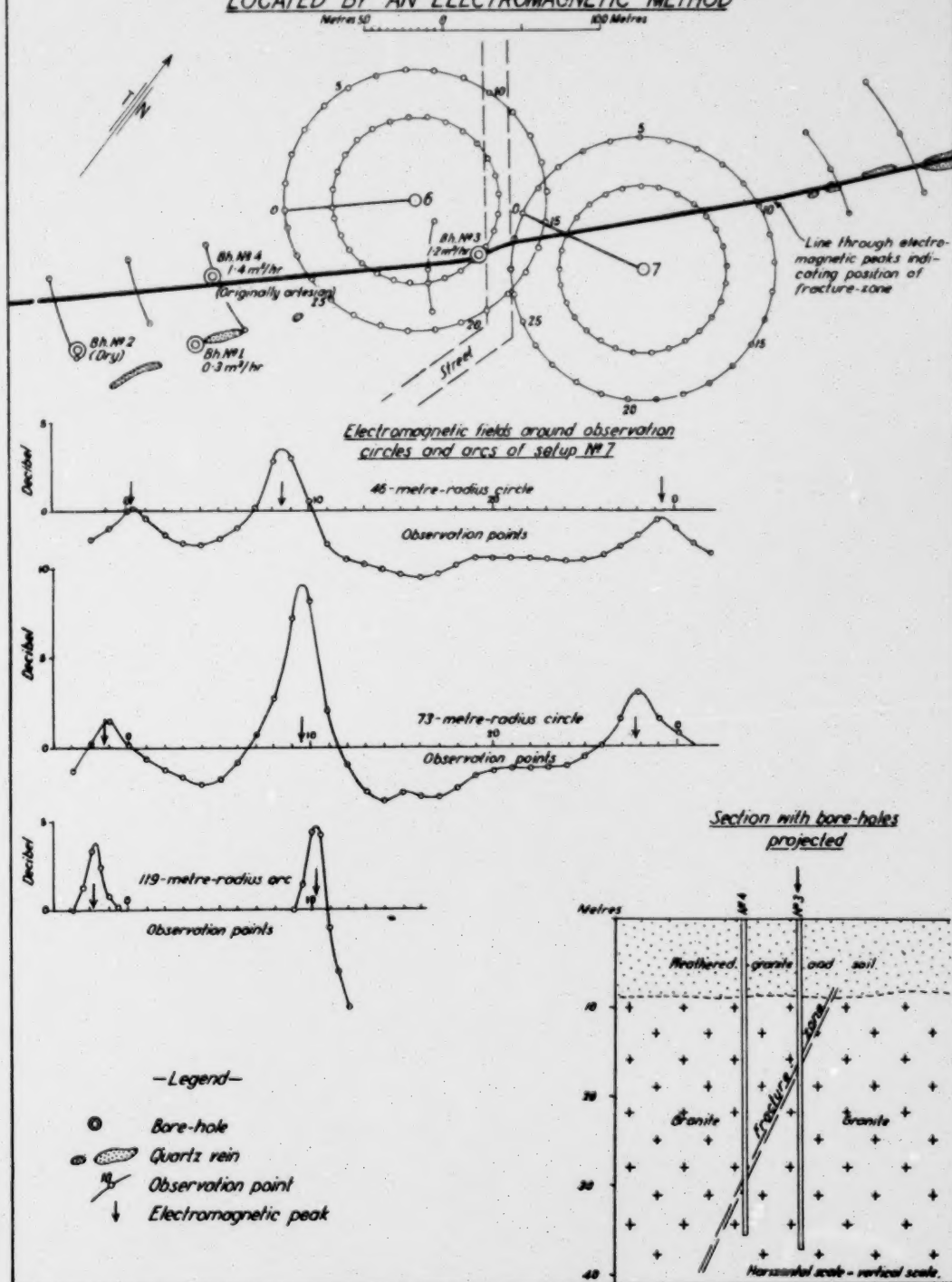


Figure IX





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UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.1.2

United Kingdom

A STUDY OF THE REQUIREMENTS FOR STAFF,
EQUIPMENT AND TRAINING
FOR A NATIONAL CARTOGRAPHIC CENTRE

By Colonel R. T. L. ROGERS,
M. A., F. R. I. C. S.,
Fairey Air Surveys Ltd

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A STUDY OF THE REQUIREMENTS FOR STAFF, EQUIPMENT
AND TRAINING FOR A NATIONAL CARTOGRAPHIC CENTRE

by Colonel R.T.L. ROGERS, M.A., F.R.I.C.S.,
Fairfax Air Surveys Ltd.

1. The designation "National Cartographic Centre" is intended to mean a national Survey Department responsible for the provision of the basic survey data and all requirements of maps and other survey services for the country concerned. Good Maps compiled from up-to-date topographical and engineering surveys are an essential requirement for planning a country's development, for the execution of development projects such as communications, power, irrigation and town planning, and for the exploitation of its natural resources. As the efficient organisation of a Survey Department has an important influence on requirements of staff and equipment, this study will also consider that vital aspect.

2. It is usual for a Survey Department to be a government organisation mainly because of the importance to national development and security of the services rendered by the Department. For this reason it is very necessary that newly independent under-developed countries should establish an efficient national Survey Department without delay. Because the timely provision of survey data is so important for a country's economic development, it is often necessary for the production of the Survey Department, at least in its early stages, to be supplemented by having mapping carried out on contract by experienced commercial organisations. Several such organisations exist and these have been carrying out mapping projects of all types, on an international basis, for the past fifteen years or so.

3. Duties of a Survey Department:

In general, the objects and duties of a national Survey Department are as follows:-

- (a) Survey Framework. The establishment of the basic survey framework of the country consisting of an evenly distributed series of permanent points whose positions on the earth's surface and heights above sea level are accurately known. In most countries certain framework data already exists and one of the first duties of the Department would be the collection and collation of such data and the planning of its orderly completion.

(b) Topographical Mapping. The planning and execution of basic topographical map series to cover the whole country.

(c) Engineering Surveys. The undertaking of large scale engineering surveys required for specific development projects.

4. Additional Duties:

In detailing the duties of the Survey Department the specific requirements and circumstances of individual countries must, of course, be considered. The following additional and important types of surveys may well be included in the general duties of the Department:-

(a) Cadastral Surveys. In order that an efficient system for the measurement, delineation and recording of individual land holdings can be established, it is necessary for this specialised type of land survey to be carried out. It provides the basic data necessary for the registration of ownership of land and for land tax purposes.

(b) Geological Surveys. These are most important for the planned exploitation of a country's mineral resources. As the topographical map provides the basic medium on which geological information is recorded, this type of survey is often included among the duties of a newly formed Survey Department. At a later stage, however, it is probable that a separate Geological Survey Department would be formed.

5. Photogrammetric Mapping:

The basis for modern surveys of the land is almost invariably the vertical air photograph and a national Survey Department should be planned to use this medium almost entirely for mapping of all types and scales. The science of accurate measurement from air photographs and the preparation of maps either with or without contours by this means is known as "photogrammetry". This Study, therefore, pre-supposes that photogrammetric techniques will be used for all mapping carried out by the national Survey Department.

6. Advice and Consultancy Services:

In some countries there exist educational institutes which can provide advice on a consultancy basis and also training facilities in all branches of photogrammetric mapping. These institutes provide facilities for either the training of personnel in their own establishments or for sending instructors to work in newly formed national Survey Departments. They would also act as consultants in advising a country on the formation, organisation, equipping and staffing of a Survey Department. Some commercial organisations mentioned in Paragraph 2 also provide similar facilities and one such organisation is known to have taken full responsibility, as consultants, for the formation and initial operation of a National Cartographic Centre. Countries who are considering the establishment of Survey Departments would be well advised to employ one of the organisations mentioned above in order to ensure that the new Department is properly organised to meet the country's particular requirements, that their personnel are trained by experienced instructors and that the best advice is available on equipment and operational organisation.

7. Organization of Survey Department:

Photogrammetric mapping techniques lend themselves to centralized production. Unless internal national policy or the size or the administrative composition of a country dictate otherwise, it is recommended that all the map production equipment and potential of a Survey Department should be centralized. In this way the Department will operate with maximum efficiency and economy. A partial exception to this might be the desirability, in countries of large area, of having provincial or other geographically de-centralized offices as field headquarters for framework control parties and other field operations. If the Department has a Cadastral Survey Division it will certainly be necessary to have provincial headquarters for both the cadastral field operations and for the preparation and possibly the storage of cadastral records. In addition to the administrative wing, it is recommended that a Survey Department should be organized into the following technical divisions; each with its necessary complement of divisional manager and section supervisors:-

(a) **Photographic Division.** It is not usual for a national Survey Department to operate its own aircraft for air photography. Economic and operational considerations usually influence the decision to have all air photographic requirements for the Department met, either by the national Air Force, or by contract with commercial air survey organizations. The Photographic Division, therefore, only provides facilities for printing and enlarging from air photographic negatives, for the making and copying of air photo mosaics and for the operation of a library containing films and prints of all air photographic coverage of the country.

(b) **Control Division.** This division provides the basic framework control data required for all types of mapping and includes a section for carrying out the computations involved in the provision of this data. The Division is also responsible for the collection of such "field" information as geographical names, classification of routes, 'man made' structures, etc., and additional data which cannot be obtained from air photographs.

(c) **Mapping Division, which is sub-divided into:-**

- (i) Photogrammetric Plotting Section.
- (ii) Compilation Section
- (iii) Fair Drawing Section.

The Plotting Section, using different types of photogrammetric plotting machines, produces the basic maps direct from the air photographs. The Compilation Section projects these 'plots' on to standard map sheet format and prepares them for the Fair Drawing Section which produces the originals of the final map sheets.

(d) **Map Reproduction Division.** This Division prints the map sheets in quantity and in colours, as required, using photo-lithographic equipment and processes from the 'fair drawn originals' produced by Section (c)(iii) above.

8. Staff:

(a) Requirements of staff fall into two main categories, professional and technical. Professionally qualified personnel should fill senior executive posts in the Control and Mapping Divisions. In addition, it is desirable that such personnel should also comprise a proportion of the land surveyors in the Control Division and the photogrammetrists in Section (i) of the Mapping Division.

- (b) The following important trades would be classed as 'technical' and in order to be so employed personnel should complete specialized training courses:

- (i) Photographic Division: Photographer, Mosaicer.
- (ii) Control Division: Land Surveyor, Computer.
- (iii) Mapping Division: Photogrammetric Plotting Section -
Photogrammetrist, Machine Operator.

Fair Drawing Section -

Draughtsman (Scriber), Type Composer.

- (iv) Map Reproduction Division: Process Photographer, Photomechanical
Processor, Lithographic Printer.

- (c) Before receiving training necessary to obtain professional qualifications as Land Surveyors and Photogrammetrists, personnel should have been educated up to at least university entrance standard with particular emphasis on mathematics and science. For the technical trades it is also desirable that personnel should have completed their secondary education, again with emphasis on mathematics and science. There are certain technical trades, however, for which personnel could be accepted for training with lower basic educational standards. The relaxation of these standards depends mainly on the quality of the personnel and such trades would include those in the Photographic Division, Draughtsmen (Scribers), Type Composers, certain photolithographic trades, and Photo Interpreters.

9. Training:

- (a) It is probable that under-developed countries would not have facilities for providing professional training and qualifications in their own countries. In these cases it is recommended that selected personnel should be sent to foreign technical institutes where they could obtain the necessary qualifications. On returning to their own country such personnel would form the technical 'back bone' of the new Survey Department.
- (b) For the other technical trades, while it would be desirable for 'key' personnel to have training abroad, it is quite possible to conduct training courses in the country concerned. Instructors and general advice on a consultancy basis could be obtained from foreign organizations as mentioned in Paragraph 6 above. It is, of course, essential that instructors so provided should be experts in their professions and trades, and that they should have had instructional experience on projects of a similar nature. Such experience would have included the preparation and implementation of syllabi for the various training courses.
- (c) Assuming that trainees have the basic educational standards mentioned in Paragraph 8(c) above, the following minimum training periods are recommended before trainees are employed on production:-

- (i) Land Surveyor, Photogrammetrist, Machine Operator,
Lithographic Printer and Process Photographer .. 1 year
- (ii) Photographer, Photomechanical Processor,
Map Compiler 6 months
- (iii) Draughtsman (Scriber), Mosaicer, Photo
Interpreter, Computer 3 months.

The above periods assume that full time training has been carried out by qualified instructors based on a syllabus prepared by experienced Consultants.

- (d) It is recommended that the number of trainees per instructor should not exceed ten. It is also desirable that foreign instructors should be assisted by

technically qualified personnel of the country concerned and the obvious choices for these assistants would be those personnel who have completed professional and technical courses abroad. It is, therefore, necessary to select such personnel and send them to overseas technical institutes at least a year before it is desired to start the full scale national training programmes.

- (c) In conducting a series of technical training courses as envisaged above, it is recommended that the following important principles should be adhered to:

- (i) Trainees should be subjected to continuous and whole-time courses in strict accordance with the syllabus, and they should not be required to perform any other duties during the training period.
- (ii) Trainees should be immediately removed from any course if the instructor confirms their unsuitability for the particular trade for which the candidate has been selected. Extra trainees should be selected at the beginning of each course to provide for this type of 'wastage' due to unsuitability.
- (iii) On no account should trainees be employed on production until the full course has been completed and the instructor has recommended their trade qualification. If necessary, trainees may have to repeat a particular course before they can be certified as fit to be employed on production work.

- (d) For a balanced Survey Department, designed to carry out topographical mapping and also large scale engineering surveys normally required for development projects, the following ratios of the major professions trades are suggested. These ratios assume that some modern topographical maps exist already, that priority is to be given to mapping for development projects and that no systematic cadastral mapping programme is to be undertaken until the new Department has been in full production on other types of mapping for at least three years:

(i)	Land Surveyors	3
(ii)	Photogrammetrists and Machine Operators	5
(iii)	Draughtsmen/Scribers	6
(iv)	Photographers	2
(v)	Map Reproduction Personnel	2
(vi)	Computers	1

To explain the application of the above ratios, if the number of land surveyors was 18, then the approximate number of Photogrammetric machine operators should be 30, draughtsmen 36, and so on.

10. Equipment:

- (a) The following major items of equipment are suggested, the numbers of individual items depending on the required rate of production of different types of mapping:

- (i) Field Survey Equipment. In addition to standard theodolites and levels (both geodetic and topographical), high precision distance measuring equipment such as Tellurometers and/or Geodimeters should be provided.
- (ii) Photogrammetric Plotting Equipment. First and probably also second order plotting machines would be required. If small scale topographical mapping is to be undertaken, and if air photography at a

suitable scale is likely to be available, some third order machines would also be desirable and economic. A proportion of the plotting machines should be suitable for aerial triangulation and it is recommended that this proportion should be about 1 to 10. For special operations such as cross-sectioning, some of the first order machines should be fitted with automatic co-ordinate printers. If analytical aerial triangulation is to be undertaken, a first order stereo-comparator would also be required.

- (iii) Photographic Laboratory Equipment. In addition to standard contact printers and enlargers, one or more precision rectifying enlargers and some electronic contact printers are recommended.
- (iv) Map Reproduction Equipment. A precision process camera, preferably of the automatic scaling type, standard photo-mechanical equipment and automatic feed offset printing machines would be required. The number of copies of map sheets to be printed and the number of colours will determine the most satisfactory type of printing machines and whether they should be single or multi-colour.
- (v) Computing equipment. Standard computing machines will be required. Although it is doubtful if the size of the Department would justify the purchase of an electronic computer, it would be advantageous if the services of such a computer were available to the Department on a part-time basis.
- (vi) Map Compilation Equipment. For this section the major requirements are magnifying stereoscopes and a co-ordinatograph.
- (vii) Drawing Office Equipment. As the majority of the fairdrawing will be carried out using the 'scribing' process, standard sets of scribing tools would be needed. For composing and letterpress required on map sheets, some form of phototypesetter would be preferable to using hand lettering procedures.
- (b) Supplies of photogrammetric plotting equipment are strictly limited and there are, at the present time, delays of up to two years in deliveries of certain first order equipment. Orders must, therefore, be placed well in advance of requirements and account must be taken of this when planning the phased build-up of a Survey Department.
- (c) For training purposes, it is recommended that the more simple anaglyphic type of equipment should be obtained. This is second order equipment and would ultimately be included in the productive potential of the Department. Deliveries of this equipment are considerably better than for first order machines, but even so 6 - 8 months' delay is likely.

11. Production:

- (a) It is again emphasised that it is a mistaken policy to begin productive work before the training syllabus has been completed and personnel can be relied upon to produce accurate work. Map making is a precise science and the quality of the final map sheet depends on the skill and reliability of the series of individuals responsible for each stage of the work. One error in the map makes the whole sheet suspect, and it is therefore essential that each person involved in its production should be qualified in his (or her) particular trade.. This can only be achieved after thorough training.
- (b) Efficient map production requires sound organization and planning. The basic material is the air photograph which can only be obtained in suitable weather,

usually occurring at particular times of the year. The framework control is also dependent on weather, but not to such a degree as is the air photograph. The execution of a successful map production programme therefore requires a considerable amount of planning and the close co-ordination of all phases of the operation. Even after the basic data is available in the headquarters of the Department, close divisional and inter-divisional co-ordination is necessary so that production can continue smoothly from the basic data through the plotting, drawing and the final printing stages. This can only be achieved by planning, co-ordination and overall control.

- (c) As an aid to future production planning, and also for cost analysis, it is recommended that detailed job records, on a man/hour basis, should be kept by each Division and Section to include all stages of the work. The technical planning office should maintain a statistical section to collect and collate this data.

12. This paper is intended to indicate the essential role of a National Survey Department in the economic development of a country and to emphasise various matters which must be considered when planning the creation of such a Department. There is a fund of experience and knowledge existing in certain national and international organizations, and it is strongly recommended that any country considering the formation of a national Survey Department should avail themselves of this advice and experience, without delay.



**CONFÉRENCE DES NATIONS UNIES
SUR L'APPLICATION DE LA SCIENCE ET DE LA TECHNIQUE
DANS L'INTÉRÊT DES RÉGIONS PEU DÉVELOPPÉES**

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Point de l'ordre du jour : A.5.1

Sénégal

**POLITIQUE D'EXPLOITATION
DES RESSOURCES MINÉRALES
AU SENEGAL**

Par L. ALEXANDRENNE,
Ingénieur Géophysicien
Directeur des Mines
et de la Géologie du Sénégal,
Dakar

Les mémoires rédigés à l'intention de la Conférence des Nations Unies sur l'application de la science et de la technique dans l'intérêt des régions peu développées sont des documents de travail. Ils sont publiés tels qu'ils ont été présentés et les assertions et opinions qu'ils contiennent sont celles de leurs auteurs.

NOTES

1. Les mémoires choisis pour être présentés en séance générale pourront être obtenus à la Conférence dans les langues officielles suivantes des Nations Unies: anglais, espagnol, français et russe.

2. Les mémoires choisis pour être présentés en séance spéciale pourront être obtenus à la Conférence dans l'une seulement de ces langues officielles.

3. Les résumés qui ont été rédigés pour tous les mémoires par les auteurs de ceux-ci pourront être obtenus à la Conférence dans les langues officielles suivantes des Nations Unies: anglais, espagnol, français et russe.

4. Préalablement à la Conférence, les mémoires et les résumés ne feront pas l'objet d'une distribution générale mais d'un tirage restreint destiné aux délégations des gouvernements et autres participants officiels. La publication et la distribution générale des actes de la Conférence s'effectueront conformément aux règles et pratiques agréées par le Comité des publications des Nations Unies.

POLITIQUE D'EXPLOITATION DES RESSOURCES MINERALES AU SENEGAL

par L. Alexandrenne, ingénieur géophysicien,
directeur des Mines et de la Géologie du Sénégal, Dakar

I) Etude et évaluation des ressources minérales

A) Etude:

Comme le mentionne le résumé provisoire, le Sénégal comprend deux entités géologiques: le Sénégal Oriental et le Bassin sédimentaire.

1°- Le Sénégal Oriental.-

a) Rappel des Travaux antérieurs

- D'une part ces travaux étaient axés sur la cartographie de la région et exécutés dans le cadre du levé de la carte géologique au 500.000e. Ceux-ci fournirent une vue d'ensemble du contexte géologique en même temps qu'ils mirent en évidence des indices de minéralisation.

- D'autre part récemment on s'orienta vers des zones avec des formations géologiques favorables à une minéralisation. La cartographie géologique ainsi élaborée a permis de localiser un certain nombre d'indices sans intérêt économique.

b) Travaux en cours: Ces travaux intéressent deux secteurs

- La Région Sud de la Falémé
- La Région Ouest de la Falémé.

b1 : Région Sud Falémé: Cette région occupée essentiellement par des formations birrimiennes est couverte d'importantes formations latéritiques rendant impossible la prospection classique à vue d'où l'on décida une étude géochimique des latérites. Dans le même temps une étude détaillée des indices de plomb fut entreprise.

b2 : Région Ouest Falémé: Ce secteur a été l'objet d'une prospection au 50.000e. L'étude des échantillons ramassés est en cours et il est trop tôt de tirer les conclusions définitives qui s'imposent. Cependant elle a permis la localisation de nombreux massifs granitiques soit syntectoniques soit post-tectoniques.

c) Projet de prospection pour 1962-1964:

Trois méthodes différentes vont se succéder:

1 : Prospection systématique au 50.000ème
basée sur les cartes photogéologiques - préparées à l'avance et accompagnée de prélèvement géochimiques et d'essais alluvionnaires.

2 : Prospection sélective géochimique et alluvionnaire

La méthode précédente a mis à nu des zones favorables soit par la présence d'indices soit par les formations géologiques; ces zones sont le plus souvent masquées par un recouvrement latéritique important dont seule la géochimie permet d'aborder l'étude.

La prospection alluvionnaire du diamant sur les terrasses est aussi envisagée.

3 : Prospection géophysique aéroportée:

Celle-ci comporte l'emploi de deux méthodes.

a) La Magnétométrie aéroportée en vue de rechercher des minerais magnétiques.

b) La Radiométrie destinée à compléter nos connaissances sur la cartographie géologique de la Région.

Cette campagne vient de se terminer. La carte provisoire des anomalies détectées suscite quelque espoir mais il est encore prématuré d'avancer des hypothèses valables. Il faut attendre la remise définitive du rapport et il sera possible à ce moment là, compte tenu des résultats obtenus, d'orienter les travaux ultérieurs. Cette étude pourrait mettre en évidence des extensions du gisement de fer de la rive Ouest de la Falémé - ou déceler d'autres amas magnétiques.

2°- Le Bassin Sédimentaire.-

Outre les recherches d'hydrocarbures, des substances utiles intéressantes sont à signaler dans le bassin sédimentaire, ce sont : - l'ilménite provenant des sables noirs des plages situées au Nord-Est et au Sud de Dakar et aussi en Casamance, - les phosphates de Lam-Lam et Fallo exploités par Péchiney, et ceux de TAIBA mis en valeur par la Cie Sénégalaise des Phosphates de TAIBA, - La pierre à chaux, les matériaux de construction et de travaux publics, les argiles industrielles et des indices de combustibles minéraux.

Une première nécessité est d'en connaître l'intérêt et l'importance exacte. Des investigations sont poursuivies dans ce sens actuellement.

B) Evaluation des Substances Minérales

1 - Le Sénégal Oriental:

Les travaux de cartographie géologique effectués d'abord au 500.000e puis au 200.000e, suivis de travaux de prospection ont apporté des renseignements complémentaires sur le contexte géologique permettant ainsi de localiser un certain nombre d'indices:

- molybdène, cuivre, plomb et or dans les localités de Tenkoto et de Ouessa.
- colombo-tantalite dans la Région de Diambaloye
- manganèse dans la Région d'Alinguel
- lithium et étain au Nord Est de SARAYA
- fer sur la rive Ouest de la Falémé (dont 40 millions de tonnes de bonne qualité titrant 57 à 63 %)

2 - Le Bassin Sédimentaire:

a) L'Ilménite: il a été l'objet d'une prospection pendant ces dernières années et a donné lieu à une exploitation. Les réserves sont importantes.

b) Les Phosphates: Les prospections entreprises ont révélé l'existence des gisements de TAIBA et LAM-LAM qui sont actuellement exploités. On peut s'attendre à découvrir d'autres gisements. En effet des indices ont été signalés dans la vallée du Fleuve et en Casamance.

c) Les Matériaux de construction et de travaux publics: Un inventaire systématique de ces substances vient d'être entrepris et sera matérialisé par une carte géotechnique au 500.000e localisant l'emplacement de ces roches, leur tonnage, les moyens d'accès et aussi les principales qualités des roches rencontrées. Quant aux argiles industrielles, elles sont susceptibles de permettre la création d'industries locales ou même de fournir des produits finis pour l'exportation.

d) Combustibles minéraux: Les recherches entreprises par différentes sociétés ont abouti à la découverte de microgisements sans intérêt économique.

II) Elaboration d'une politique minière nationale

Le Gouvernement du Sénégal soucieux de l'avenir économique du pays a décidé d'élaborer une politique minière nationale destinée à inventorier toutes les ressources minières de son sous-sol. Cette politique est contenue dans le Plan Quadriennal de Recherches Géologiques et Minières.

Récemment un Code Minier Sénégalais est intervenu donnant aux entreprises minières privées un cadre réglementaire solide pour leurs activités de prospection, de recherche et d'exploitation. Cette charte faisant appel dans une certaine mesure aux capitaux privés, il a été utile de mettre sur pied un Code des Investissements accordant des garanties économiques et juridiques aux investissements consentis par les Sociétés. En particulier la plus grosse exploitation du Sénégal, celle des Phosphates de TAIBA bénéficie d'une fiscalité allégée.

Ce Plan Quadriennal de Recherches Géologiques et Minières sera financé par la Fonction Publique soit sous forme directe, soit sous forme d'aide extérieure (Fonds Assistance Communauté, Fonds Européen de Développement, Fonds Spécial ONU etc...).



UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

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World Meteorological
Organization

ARTIFICIAL INCREASE OF RAINFALL

By Dr. L. J. BATTAN,
S. N. NAQVI,
Prof. V. Y. NIKANDROV,
and Dr. O. VITTORI-ANTISARI, Chairman
Commission for Aerology Working Group
on Clouds and Hydrometeors

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

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3. Summaries of all papers, as submitted by contributors, will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

4. Papers and summaries will not be available for general distribution in advance of the Conference. They will be published in advance in limited quantities only for the use of delegations of participating governments and of other authorized participants. Post-Conference publication and general distribution of the Conference Proceedings will follow United Nations practices as laid down by the United Nations Publications Board.

ARTIFICIAL INCREASE OF RAINFALL

By

Commission for Aerology Working Group on
Clouds and Hydrometeors

(Dr. L.J. Battan
Mr. S.N. Naqvi
Prof. V.Y. Nikandrov
Dr. O. Vittori-Antisari (Chairman))

1. Introduction

(a) The revolutionary prospects of artificial rain-making have attracted the serious attention of all concerned, particularly the atmospheric scientists. The prospects of removing, or at least minimising water deficiency of vast tracts of land surface is so full of promise that numerous attempts have been made in recent years in various countries for producing artificial rain for economic advantages.

(b) The aim of this report is to present a brief objective survey of the present state of knowledge of techniques for attempting to produce artificial increases of precipitation. In 1955, the World Meteorological Organization published Technical Note No.13 giving a detailed discussion of the physics of clouds and summarizing existing knowledge on all aspects of cloud modification. Since the publication of Technical Note No.13, a substantial amount of new information has been accumulated. A large number of cloud seeding projects have been conducted. However, the overall views of this problem as presented in that Technical Note still have general validity.

(c) During the past decade, knowledge of the processes occurring inside clouds has increased significantly as a result of theoretical and experimental investigations. Nevertheless it still is not possible to evaluate quantitatively the processes which lead to the formation of precipitation. Therefore we still lack sufficient information for assessing by means of physical methods (therefore, absolutely objective ones) the effects of seeding on large-scale experiments. For this reason, this report will emphasize the part played by statistical methods for evaluating rain-making experiments.

2. Basic Knowledge

(a) The natural processes which lead to the formation of precipitation inside clouds and which represent the foundations on which techniques of seeding are based, will not be discussed here in any detail. The reader is referred to the appropriate literature on this subject.

(b) Research in cloud physics has demonstrated that there are two processes for the production of precipitation:

(i) When an ice crystal is introduced in a volume of supercooled clouds, it grows at the expense of surrounding droplets. The growth takes place by means of water vapour diffusion followed by the capture of droplets colliding with the falling crystal. The precipitation particles can reach the ground as a snow crystal or a raindrop depending on the value of the temperature in the lower layers of the atmosphere.

(ii) In a volume of cloud a large droplet (30 to 50 microns radius) grows by coalescence with smaller droplets until it becomes a raindrop.

(c) It should be noted that in the evaluation of the efficacy of seeding techniques, the microphysical aspects of the precipitation processes should not be over-emphasized. The spectrum and the concentration of the particles (nuclei droplets and crystals) are not the only parameters to be considered. It is essential to realize that the macrophysical features of the cloud system play an important rôle in the precipitation process. It is clear that the quantity of rain that falls depends on the properties of the atmosphere which governs the growth and maintenance of the clouds.

(i) Various studies have shown that the precipitation efficiency of different raining cloud systems may vary from very low to 100 per cent. When the rate of water vapour deposited on particles in the cloud is equal to the quantity of precipitation falling out of the cloud, there is no storage of water inside the cloud, and the precipitation efficiency may be said to be 100 per cent.

(ii) On the other hand, when the rate of water vapour deposited on the particles is greater than the quantity of precipitation released by the cloud, there is storage of water in the cloud, and the precipitation efficiency is less than 100 per cent. In this circumstance, cloud seeding may augment the natural processes and lead to an increase in rainfall.⁽¹⁾

(d) It should be recognized, when considering the use of cloud modification techniques, that the physical properties of the clouds should be well known. We know, for example, that there are important differences in the

(1) It is possible, in the case of 100 per cent efficiency, that the artificial production of ice crystals may lead to a rapid release of the latent heat of fusion of water, causing an increase of the updraft velocity and an increase in precipitation.

cloud and precipitation processes in local convective clouds and widespread cloud systems produced by frontal lifting. It has already been noted that cloud temperatures are important in the precipitation processes. Because of the fact that there are large differences in cloud types and amounts from one region to the next, it is not usually possible to extrapolate the results in one region to another region without first having made fairly extensive series of observations of the clouds. It is strongly urged that provisions be made for collecting appropriate special observations before any cloud seeding is attempted.

3. Seeding Techniques

(a) Seeding substances

(i) Clouds composed of water droplets supercooled to temperatures of -15°C and lower are commonly found in the atmosphere. In order to stimulate precipitation, ice crystals should be produced inside the clouds at lower altitudes than would be the case if the ice crystals develop naturally. The threshold of nucleation can be raised to higher temperatures by means of solid carbon dioxide and finely divided silver-iodide particles. The threshold of the nucleation of CO_2 and AgI are 0°C and -7°C respectively. Other chemical reagents have also been tested as ice-forming nuclei but their thresholds are at temperatures below -7°C .

(ii) For the production of large cloud droplets which can grow efficiently by coalescence, hygroscopic salts and water drops have been dispersed in clouds.

(b) Production of seeding agents

(i) Solid carbon dioxide has been released in clouds in the form of small pellets. The deeper the supercooled parts of the clouds, the larger should be the diameter of the CO_2 pellets released from above. Under the best seeding conditions the rate of production of ice crystals by means of CO_2 has a maximum of the order of 10^{16} crystals per gram.

(ii) Many types of silver-iodide generators have been designed and constructed. It is believed that the largest rate of production of silver-iodide particles, which can be achieved only with great difficulty and highly-refined techniques, is 10^{14} particles per gram of silver-iodide. In general, silver-iodide is vapourised at a high temperature either in a flame or in a hot chamber or as a result of the explosion of substances containing a silver-iodide mixture. The minute particles having diameters ranging from 0.01 to 1 microns are formed by sublimation from the vapour phase. In some experiments, AgI particles are produced as a result of evaporation of droplets of highly volatile liquids containing a colloidal suspension of AgI .

(iii) Hygroscopic particles have been obtained by grinding salt into fine powder or by the spraying of saline solution.

(c) Methods of introducing seeding substances

(i) Dry ice, a relatively inexpensive substance, is usually released from airplanes. New techniques for obtaining particles of CO_2 allow controlled rates of seeding. Although dry ice can be very effective for ice-crystal formation in supercooled clouds, the necessity of using airplanes, at the present time, can limit its application in large-scale experiments.

(ii) Silver-iodide has been released from networks of ground-based generators, from airplanes and rockets. With all types of seeding techniques it is important to consider the transport and diffusion of the silver-iodide particles. In particular, the particles produced at the ground can be transported into clouds only when there is strong convection or a pronounced orographic barrier exists. There is no effective control of the trajectory of the silver-iodide smoke plume when the generators are located on flat terrain. In various experiments, silver-iodide particles have been released from airborne generators on airplanes flying up-wind from the clouds. In this case also, it is essential that the diffusion and transport of the particles by air motions be considered.

a. An important problem encountered when silver iodide particles are released up-wind from the clouds is caused by the decay of the ice-forming properties as a result of exposure to sunlight. The decay rate may be of the order of a factor of 10 per hour.

b. Silver-iodide can be transported directly into the clouds by rockets. An explosive mixture of silver-iodide is placed in the head of the rocket. When the mixture explodes, a high local concentration of silver-iodide particles is produced. The spread of these particles through the cloud is determined by diffusion and turbulent air motions in the cloud.

(iii) Hygroscopic particles have been dispensed from the ground, airplanes and rockets. When the particles are released from the ground a significant fraction of the material is lost. The very large particles fall to the ground in the vicinity of the generator. The uncertainties connected with the trajectories of salt are even more serious than is the case for silver-iodide because the salt particle diameters are much greater than those of the silver-iodide.

4. Statistical evaluation procedures

(a) Since the late 1940's a variety of statistical techniques has been tried. Some of them have since been shown to be insensitive and have been discarded; others are still in use. In general, the schemes that have been employed can be divided into two categories: 1) those which involve only a single area over which more precipitation is wanted and which is often called the "target area"; 2) those which involve two regions, the target area and another nearby region, known as the "control area", whose precipitation is used to estimate the natural precipitation which would have fallen over the target area had there been no seeding. In the following paragraphs the prominent features of these two categories of statistical designs will be discussed briefly.

(b) Some of the early cloud-seeding tests were made by seeding over a particular area and comparing the precipitation with that which fell in the past over the same area. It has been reported by H.C.S. Thom⁽²⁾ that because of the high variability usually encountered, it would be necessary for cloud seeding to increase precipitation to about three times its medium value in order to be able to demonstrate at a convincing level of statistical significance (the 0.05 significance level) that there was an increase of precipitation. In view of the fact that, at the present time, cloud physicists believe about a 20 per cent increase is a reasonable upper limit to a possible increase, the use of a single area and a comparison of seeded rainfall with historical records, seems unlikely to demonstrate the occurrence of reasonable rainfall increases even if they actually occur.

(c) A second cloud-seeding evaluation procedure by which only one area is used, involves the seeding of approximately half the suitable cloudy periods and then comparing the precipitation on the seeded and not-seeded periods. For example, if there is a distinct diurnal maximum of rainfall, a day can be selected as the experimental unit. When suitable cloud conditions are expected, each day is either seeded or not, according to a suitable randomization scheme. By employing an objective technique for deciding when days are suitable, it is possible to design an experiment whereby one of two successive days is seeded on a random basis. The evaluation involves the study of pairs of days. The sensitivity of this type of approach depends, to an important extent, on the correlation between rainfall on the two successive days which constitute the pairs. The higher the correlation between rainfall on two successive days, the more sensitive the tests.

(d) A commonly used cloud-seeding evaluation procedure involves two nearby areas only one of which is seeded. If the precipitation quantities on the two areas are highly correlated, the precipitation on the unseeded (control) area can be used to estimate the quantity of precipitation which would have fallen on the seeded (target) area had it not been seeded. This so-called "regression-analysis technique" of predicting target rainfall has some weaknesses. First of all, it requires extensive periods of rainfall records and therefore can be applied in only a limited number of places. It is based on a mathematical model which assumes that the rainfall quantities on the two areas are drawn from a stationary and normally distributed time series. Neither of these assumptions is entirely justified. Departures of precipitation amounts from normality can be corrected in part by transforming the measured rainfall to a variable which is close to normality. This has been done by using the logarithm or the square root of the precipitation. The measured precipitation values can also be transformed to approximately normally distributed functions by making use of the finding that precipitation data is closely fitted by the incomplete gamma distribution. It is not clear, however, that this more complicated transformation is any better than the simpler ones. It has been found that when the transformed target precipitation is plotted against the transformed control precipitation, the variability of the former remains essentially constant for all values of the control

(2) Final Report of the Advisory Committee on Weather Control, Vol. II,
U.S. Government Printing Office, 8 (1957).

precipitation. Once this has been accomplished, it is possible by means of standard statistical techniques to calculate the probability that the results during seeded periods could have resulted by chance.

(e) A serious difficulty in using regression methods is introduced by time variations in the relationship between the rainfall on target and control areas. It is well-known that precipitation undergoes cycles of varying wavelengths and durations. Over a period of several years area A may have more precipitation than area B, possibly because of a prevailing wind pattern favouring deep-cloud formations over A; during the next several years the prevailing pattern may shift so as to give more rainfall over area B. In order to take such temporal variations into account, long periods of records are needed. Unless they exist, the seeding evaluation scheme is subject to some question. In some cases it may be possible to reduce the effects of weather cycles by stratifying the data according to a system of storm types and developing a regression line of target versus control transformed precipitation for each storm type. Unfortunately, in most regions the quantity of historical data is not sufficient to allow for much stratification.

(f) In the preceding two sections the evaluation involved the comparison of rainfall over two fixed areas. In some programmes, the location of the target and control areas are shifted according to the wind pattern and other meteorological factors. In these tests the areas are delineated at the start of the seeding period and then one or the other, or neither of them, is seeded according to a suitable randomization scheme. The average precipitation over the seeded and not-seeded areas can then be compared. Clearly, a large number of raingauges is needed if the tests are concerned directly with the effects of seeding on precipitation reaching the ground.

(g) A randomized seeding programme is one in which the test occasions are divided into two groups, one of which receives the seeding treatment and the other of which does not, the selection of cases for the two groups depending solely upon random events. The evaluation of the effect of the treatment is then obtained from the difference in precipitation in the two sets of data.

(i) The effect of randomization is to provide a simple and complete guarantee of a valid interpretation of the results of a test, regardless of disturbances and uncertainties arising from incomplete control over the conditions of the test⁽³⁾. In previous sections it was noted that errors may result from bias in the mode of operation or method of evaluation, and may also arise from the effects of selection of covariates, and from the general failure of weather sequences to behave as stationary time series. Methods of minimizing such errors have been discussed, but it has also been pointed out that at present there is no way of eliminating them entirely, and no reliable way of determining their magnitude. Randomization is an effective way of placing the experimentation on a meaningful basis.

(3) Fisher, R.A.: The Design of Experiments, 2nd ed. Oliver and Boyd, Edinburgh, 22 (1937).

(h) Statistical tests

(i) As noted in paragraph 4(d), when employing regression methods of comparing target and control precipitation, it is necessary to transform the precipitation values so that the variability of target precipitation remains constant for all values of the control precipitation. This step is necessary because regression theory is valid only for normally distributed variables.

(ii) The difficulty of non-normally distributed variables can be overcome by employing non-parametric tests which, by definition, do not require a knowledge of the distribution of the test variables.

(iii) It is essential to recognize that in order for any cloud-seeding experiment to yield convincing statistical results, it is necessary that the technique of data collection be compatible with the technique of data analysis. For example, if it is decided to use a randomization scheme whereby one of two suitable pairs of days is seeded randomly, the tests of significance should be made by means of a procedure which examines the difference between the rainfall on the pairs of days.

(iv) Statistical techniques of evaluation are essential because of our poor understanding of natural precipitation processes and our inability to accurately predict the quantity of rainfall to be expected from any cloud or cloud system. Unfortunately, statistical evaluation techniques are usually insensitive and require large quantities of data before valid inference can be drawn. This fact has made it difficult to resolve the questions about the effects of cloud seeding on precipitation.

(v) Clearly, it is imperative that increasing attention be devoted to studies of natural cloud and precipitation processes so that evaluation of various cloud-modification techniques can be made by physical, as well as by purely statistical methods.

5. Conclusions

(a) The small scale experiments have clearly demonstrated that seeded clouds are significantly modified physically but for evaluation of the increase in precipitation to the ground resulting from the cloud modification, more severe statistical tests have to be applied.

(b) A detailed survey of cloud-seeding experiments performed by means of ground-based AgI generators mostly in the United States was published in 1957 by a government committee of the United States⁽⁴⁾. The chief conclusions were the following:

(4) Final Report of the Advisory Committee on Weather Control, Vols. I and II. U.S. Government Printing Office, (1957).

"(1) The statistical procedures employed indicated that the seeding of winter-type storm clouds in mountainous areas in western United States produced an average increase in precipitation of 10 to 15 per cent from seeded storms with heavy odds that this increase was not the result of natural variations in the amount of rainfall.

(2) In non-mountainous areas, the same statistical procedures did not detect any increase in precipitation that could be attributed to cloud seeding. This does not mean that effects may not have been produced. The greater variability of rainfall patterns in non-mountainous areas made the techniques less sensitive for picking up small changes which might have occurred there than when applied to the mountainous regions.

(3) No evidence was found in the evaluation of any project which was intended to increase precipitation that cloud seeding had produced a detectable negative effect on precipitation."

(c) Conclusion (1) which has been the basis for optimism has been criticised by various statisticians on the grounds that the data employed in the evaluations were not collected by means of a randomized programme (5).

(d) Since 1957 randomized cloud-seeding programmes have been conducted in various countries: notably Australia, France, India, Israel, Italy, Japan, Mexico, Pakistan, Soviet Union, Switzerland and the United States. These tests have thus far not succeeded in demonstrating conclusively that seeding can increase precipitation by a significant amount.

(e) Reports from Australia, where randomized cloud-seeding programmes have been in progress since about 1957, have been mixed. Success has been reported in one project, and possibly a second one as well, while in the other tests the results have either been inconclusive or have shown negative results. Progress reports from several other countries have indicated increases of precipitation, but the data have not yet been published and subjected to the careful scrutiny of the scientific community.

(f) Although there is some evidence that in certain special situations it may be possible to increase precipitation, a net increase of precipitation has not been demonstrated beyond reasonable doubt. Before it can be said that the doubt has been removed, those experiments now in progress which have shown positive results, will have to be taken to their conclusions and the results subjected to the evaluation by statisticians and atmospheric scientists.

(g) It is the considered opinion of the authors of this report that increasing the knowledge of the natural processes in the clouds and the improvement of the techniques of seeding should lead to the development of effective means for increasing precipitation at the ground.

(5) Brownlee, K.A., Statistical evaluation of cloud seeding operations.
Journal American Statistical Association, 55, 446-453 (1960).



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UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.4.3.1

Sweden

PROVIDING A RAPIDLY DEVELOPING COUNTRY
WITH ELECTRIC POWER

By Hakan OFVERHOLM,
MIEE Director

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.
2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.
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Providing a rapidly developing country with electric power

Håkan Öfverholm MIEE Director

Industrial development means that less and less muscle power is required to do more and more work. Nature has provided mankind with lavish sources of energy that may be brought to serve for the purpose but usually it is not expedient to use them directly. Electricity has served as the best medium so far and the state of a country's industrial development can more or less be gauged by the amount of electricity available per capita. Table 1 gives some examples in that respect.

Norway	7003	Australia	1750
Canada	5400	Finland	1581
USA	4111	Austria	1509
Sweden	3669	Czechoslovakia	1372
Switzerland	2719	Belgium	1359
New Zealand	2263	France	1299
United Kingdom	2005	Netherlands	1166
East Germany	1900	USSR	1100
West Germany	1765		

Table 1. Electric power consumption per capita and year (1959) measured in kWh.

Electricity may be produced by thermal power with steam or gas turbines from coal, oil, natural steam or gas or for that matter in smaller quantities by diesels. Wind power and water power may be used whenever available and the latest source of energy is nuclear. So far generators are driven by the mechanical prime mover and alternating current is used for the transmission to the point of usage.

Electricity provides lighting, drives motors, heats steel furnaces, stirs the melt, turns papermaking machines and printing presses, moves rolling mills and deep shaft winches. It allows one man single handed to carry out the work that it in his forefathers time took hundreds and hundreds of men to achieve in a less technically developed period of civilization.

Interesting is of course the question of how fast such development may take place and all countries compete in that respect trying to replace human power by means of machinery thereby getting nearer and nearer what they consider to be a welfare state. Amazingly enough there however appears to be a natural limit to such development and generally the use of electricity is not more than doubled in any one country inside a decade. Table 2 shows an interesting example from Sweden and Table 3 lists the actual development up to 1961 inside the two European units EEC (the common market) and EFTA (the free trade area) together with anticipated increase up to year 1966.

1910	1	TWh = 1.000.000.000 kWh
1920	2	
1930	4	
1940	8	
1950	16	
1960	32	

Table 2. Electrical consumption in Sweden.
Increase by doubling each decade.

	EEC		EFTA		7.2 % yearly rate
1959	274.235		480.507		
1960	304.591	11 %	533.801	11 %	7.2
1961	327.430	19.5 %	574.371	19.5 %	14.9
1962	352.070	28.5 %	617.779	28.5 %	23.2
1963	377.950	38 %	663.678	38 %	32.1
1964	405.380	48 %	710.839	48 %	41.6
1965	434.470	58.5 %	761.826	58.5 %	51.8
1966	465.540	70.5 %	815.270	70.5 %	62.7

Table 3. Electrical consumption in GWh (1.000.000 kWh according to OECD) within Europe in marketing areas, EEC and EFTA. From 1962 and onwards anticipated increase. At 7.2 % yearly rate the consumption is doubled in a decade.

It appears that the availability of power and the development of industry forms kind of a vicious circle that is responsible for the limited yearly average increase. Only when electricity is available development may take place and as soon as this starts there is immediately a need for more power. The time required for acquiring and commissioning new plant and for expanding industry limits the speed of development and there is no doubt that centralized governing such as practiced for instance in Russia may show greater achievements by planning right ahead both for electric power and industry to develop in parallel. The Russians thus claim a trebling inside each decade to be possible as against doubling when development takes place freely as in other countries. This fact is of course of greatest interest to a rapidly developing country wanting to show results and biggest possible results with smallest

possible time delay.

The next question is then to find out how much electric power is required for a certain industrial development. Here it has to be borne in mind that in ordinary communities the use of electricity for other purposes than industry rises rapidly with the state of welfare brought about by the development. OECD in their enquiry No. 12 have found that the total call for electricity rises approximately with the square of the industrial production i. e. if this is doubled, four times as much electricity is consumed. This fact is also borne out by the fact that industry produces much more per head in countries with a lavish supply of electricity than in countries less fortunate in that respect.

	\$ per capita and year	Electricity available
USA	17700	4111
Sweden	9200	3669
Switzerland	6900	2719
United Kingdom	6000	2005
West Germany	5400	1750

Table 4. Production per capita within the large electrical power industries in the world as compared with the amount of electricity available per head (table 1).

Table 4 shows comparative figures from the largest electrical industries in the world taken from Fortune's list of firms and selected so as to obtain somewhat similar working conditions. Thus naturally a car maker buying most of his parts elsewhere cannot possibly be compared with a ball-bearing maker manufacturing his product right from the beginning. It is quite evident from the comparison that a higher rate of productivity is entirely dependent on power resources and it is thereby proved how extremely important the availability of ample power resources is to a country wishing to develop rapidly.

As mentioned before the diesel engine is the most usual prime mover when small quantities of power suffice and also in highly developed countries it is retained for standby power purposes in such cases where an unbroken supply has to be available such as for hospital, airports, telephone exchanges etc. but also for providing lighting in outlying areas where the electric network cannot reach at competitive costs. Already at a few hundred kilowatt output the capital cost, however, becomes onerous with the diesel driven alternator that does not come out cheaper per kW above a certain size and may not be able to use the cheapest fuels available.

The steam turbine although somewhat more complicated as it has to be provided with a separate boiler definitely holds its own as from 1000 kW and onwards but is supplemented by the gas turbine for cases where short time

peak load working or extremely rapid standby power is required. This prime mover is, however, not so efficient as the turbine and is therefore not put into continuous use except when gas fuels are obtained at very low cost. Neither may it be developed into larger sizes and the world record at the moment is held by the Swedish 40 000 kW gas turbine station at Västervik, Sweden. So far larger sets would not come out cheaper per kilowatt, neither show better efficiency (28 %). Development, however, takes place continuously and diesels as well as gas turbines may now be run on thicker and thicker fuels at lower and lower cost.

As load increases beyond that catered for by the smaller types of turbines it is rational to replace those with larger sets rather than to increase the number of sets. The steam prime mover is capable of such improvements as the size increases that both capital and running costs are materially reduced. In the former case a doubling may mean a reduction by 15-20 % in cost per kW installed and in the latter some 10 % reduction of fuel per kWh produced may be realized. However, there is a present limit to the latter improvement as however clever modern designers may have been, hardly more than 40 % of the calorific value of the fuel is converted into electric energy in anyone of today's plants and 45 % thermal efficiency has yet to be reached. This means a terrific waste under present circumstances and gives rise to another problem - cooling water.

Smaller plants may use cooling spray ponds for disposing of the waste heat if the plant may not be suitably placed alongside rivers or at the seaside where ample supply is available. Even then the amount of heat to be carried away may cause trouble and inconvenience as for instance with the river Thames in England cooling a large number of power stations on its way to the sea and thereby increasing considerably in temperature. The only other solution so far is the cooling tower which however provides a not inconsiderable increase in production costs and anyhow needs a certain quantity of make up water. This explains why gas turbines with their considerably smaller cooling water consumption may be preferred in desert areas for instance for gas or oil pumping plant.

In countries with a cold climate the waste heat may be used for district heating, a method very common in the whole of Scandinavia. This provides for an inexpensive combination of electricity and heat generation with consequent low costs in both instances. The method is naturally limited in its application to great cities or industries but in the latter case electricity production may also be combined with steam raising for industrial production. Counter pressure or bled turbines are used and electricity is obtained most efficiently. Particularly the cellulose industry is well served in this manner.

With larger steam turbines the technology becomes more complicated as higher pressures and higher temperatures

of the steam become economically feasible and this turns the power station into a chemical laboratory. Special steels are used to withstand the onerous conditions but if they are heat resisting they instead become extremely vulnerable to the feed water chemical treatment. Large power generation though highly economical thus requires advanced expert knowledge.

Hydraulic power is a question of harnessing streams and the storing of water which usually requires large capital but on the other hand has very small running costs. Scandinavia is particularly well developed in that respect and all kinds of plants required are there available. Of particular interest is that the rainfall usually varies in cycles in the proportion 1:2 over the years and that a rationally built plant usually provides for thermal peak load and drought standby power as it is not economical to build only for minimum flow. Sweden as an example has hydro-generating facilities for 10 % over average flow and 25 % thermal standby used however on an average only for generating a few percent of the units required over the years. ASEA is the main Scandinavian supplier of both waterwheel driven generators as well as steam turbos and gas turbines, the turbines themselves being delivered by other Swedish suppliers such as KMW, STAL-LAVAL Turbin Co. etc.

Generally speaking the capital costs for obtaining hydro-power are far more onerous than those for thermal plant but on the other hand no fuel is consumed. Countries short of, or without fuel of their own, are therefore particularly anxious to make use of their national resources and develop hydroelectric power at a preference. When due to the rapid increase in demand water power will no longer suffice nuclear power may provide a suitable replacement. So far nuclear power has not been produced at such cost as to compete neither with thermal power nor with hydro even when such plants have been given an opportunity to run continuously at full load. Average utilization is otherwise 4500-5500 hours a year or 50-65 %.

The installation of power plants requires trained staff and in the case of rapid development it may therefore be expedient to obtain assistance with this detail. British practice is to make use of consulting engineers who make the necessary preliminary investigations, specify the plant required and supervise the erection. Still more complete service is given in the case of turn-key installations where the supplier provides the plant ready erected and run up to load as well as trains the staff in the daily running schedule. With larger plants this becomes more and more difficult and it has been stated that some American utilities run their plant continuously through the years and call for the makers assistance when the equipment has to be stopped for overhaul and thereafter started again. As examples of turn-key jobs Swedish deliveries through the firm of Electroinvest to Ethiopia, Brazil and Iran may be mentioned.

With electric power once available real industrial development requires specialized plant for mining, steel making, rolling mills, cellulose factories, printing, cotton and woollen mills etc., all requiring highly developed know how. Transport problems may also be solved electrically and as is wellknown almost the entire Swedish railway system is electrified according to the now universal A. C. system. Originally the railway load was considered most important to the power system providing as it does an evening out of peaks. People do not work when they travel and vice versa and the railway thus fill the gaps when the factories rest. However, with higher development industry passes traction as a load source and the latter finally is responsible for less than 10 % of the demand. It is then important that industry and traction are fed from the same network so that the same Grid may serve both. The modern way of doing this is to feed the railway single phase at industrial frequency and to turn this into D. C. on the rolling stock by means of silicon rectifiers. Older systems run quite efficiently with A. C. motors at $1/3$ of the industrial frequency by means of substation synchronous 12 pole - 4 pole frequency converters. This has also the advantage that only balanced threephase traction load at leading power factor is imposed upon the Grid system which may not be sufficiently stable to carry considerable single phase railway loads at lagging power factor.

In the case of tubes or subways as well as remaining tramway and trolley bus lines these are fed with D. C. from silicon rectifier substations along the line.

It is evident from the above that power units which in themselves may have a useful life of some thirty years will be replaced by larger sets already within 10 years time. It is therefore wise to make arrangements for the removal of the plant to new sites after this initial period rather than to let it rest inefficiently as a standby. Diesel sets provide no problem in that respect but conventional steam turbines driving separate generators require heavy foundations to deal with the torque transmitted under normal and short circuit conditions. There is, however, one special design of turbine where the generator forms an integral part of the turbine itself and the set thus lends itself to easy removal and transport. Brazil, the Argentines, India and Poland have made use of such turbines in great number for developing load until such period that the different load centres may be joined by means of a National Grid system. The design makes use of two counter rotation turbines working in one and the same shell and the same steam flow thus passing the different turbine rings of the two prime movers alternately. The two counter rotating shafts are joined together by electrical means each carrying a generator both working in synchronism on the network as one unit. This Ljungstrom type turbine only requires a very light foundation sufficient to carry its own weight and the future transport to a new site is therefore easily accomplished. Simultaneously the relative speed of the two blade sets is twice that other-

wise obtainable (6000 rpm instead of 3000 rpm with 50 cycles, 7200 instead of 3600 rpm with 60 cycles) and the efficiency consequently reaches values otherwise not obtainable for the size of set in question. The same type of turbine has been developed right up to some 300 000 kW so that in the case of extensions the staff trained on this particular design may be retained right through.

As load reaches into larger ratings another problem is added and that is two shift working i. e. some sets have to be shut down at night and started up the next morning to provide enough night load for the remaining sets to run through. The larger the set the more difficult this problem becomes with the conventional turbine where runner and shell do not heat up at the same rate and consequently complicated apparatus and skilled staff is required to maintain the narrow clearances required for efficiency reasons. Here again the Ljungstrom design with two equal turbines providing alternate blade rows in the steam, heat up at exactly the same speed and allow more or less instant starting without supervisory instruments, apparatus or special staff. Also for standby purposes this feature is invaluable as load may be taken as fast as the boiler will allow. In the latter respect modern boilers are becoming faster and faster and a study of the Swedish underground 1 000 000 MW station Stenungsund is recommended. Two Ljungstrom sets of 160 000 kW each are there commissioned and two more of about twice that size will follow.

Less fuel, less staff and decreased maintenance follows with larger sets but the capital requirements are naturally more onerous if the plant cannot be put to full use immediately. Present day power engineers have, however, found that it pays well to be in advance of requirements as the loss of interest is anyhow offset by inflation and it therefore may be good economy to look well ahead when planning. The only thing to be held against such a line of thinking is the question of modernity and efficiency. By waiting somewhat a more modern design that will resist replacement longer may be obtained and there is also the possibility of a more rational way of taking care of the fuel being developed. However, in the case of buying one or two years in advance this possible gain may hardly offset the advantage of a somewhat larger set.

Very little has been said about the transmission of energy as it is only in later stages that this becomes a major question. However, development may be achieved by means of power sources remote to the demand and considerable savings may be obtained by joining different power centres so as to provide a common standby and a levelling out of power peaks. It must then be remembered that the transport of electricity is quite a costly matter and that therefore it is usually found cheaper to transport the fuel and then particularly if it is a question of oil or gas. However, hydro electric power plants are where they are and transport by electrical means is today's only solution

of the problem of how to bring the power to the consumer. Here again it pays to plan ahead and not to select the transmission voltage too low as not to allow for future developments. The highest transmission voltage in use is so far in the 500 000 volt range as practiced in Sweden since ten years (420 000 - 380 000 volts with 500 000 volts insulation standards) but higher voltages may become necessary for larger amounts of power to be transported over longer distances. An interesting thing is there the advent of high voltage direct current transmission which incidentally solves also the cable problem and has therefore been used for marine crossings such as the English Channel, Cook Strait, New Zealand and Sardinia to the mainland in Italy. Here the alternating current would provide great difficulties with the large capacity current of the cable and also uses a 40 % higher peak voltage than the corresponding D. C. transmission.

In the case of the English Channel the cable runs East-West with the sun and thus finds the daily peaks distributed at different periods in the two countries joined by means of the D. C. link. Theoretically such a cable right across the American Continent would take care of all the peaks in the seven hour time difference traversed without the necessity of any new generating equipment being provided. In that case an A. C. link is also possible but would involve synchronous running of the entire system with the risk of considerable overloading of the link whereas the D. C. link only transmits the power it is set to deal with.

As development goes on electricity plays a more and more important part in the production of a higher standard of living starting in a modest manner with lighting and fans, with or without air-conditioning right up to the present day completely electrified town life where manual power is substituted by mankind's servile slave electricity.



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CONFÉRENCE DES NATIONS UNIES
SUR L'APPLICATION DE LA SCIENCE ET DE LA TECHNIQUE
DANS L'INTÉRÊT DES RÉGIONS PEU DÉVELOPPÉES

Point de l'ordre du jour : A.4.3.1

France

L'UTILISATION DES GROUPES BULBES
DANS LES AMÉNAGEMENTS HYDROELECTRIQUES CLASSIQUES
ET DANS LA CENTRALE MAREMOTRICE DE LA RANCE

Par F. AUROY,
Directeur de la Région d'Equipement
Hydraulique Massif Central
et G. MAUBOUSSIN,
Directeur de la Région d'Equipement
Marémotrice à l'Electricité de France

Les mémoires rédigés à l'intention de la Conférence des Nations Unies sur l'application de la science et de la technique dans l'intérêt des régions peu développées sont des documents de travail. Ils sont publiés tels qu'ils ont été présentés et les assertions et opinions qu'ils contiennent sont celles de leurs auteurs.

NOTES

1. Les mémoires choisis pour être présentés en séance générale pourront être obtenus à la Conférence dans les langues officielles suivantes des Nations Unies: anglais, espagnol, français et russe.
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L'UTILISATION DES GROUPES BULBES DANS LES AMENAGEMENTS
HYDROELECTRIQUES CLASSIQUES ET DANS LA CENTRALE
MAREMOTRICE DE LA RANCE

par F. AUROY, directeur de la Région d'équipement
hydraulique Massif central

et G. MAUBOUSSIN, directeur de la Région d'équipement
marémotrice

A L'ELECTRICITE DE FRANCE

1. La technique récente des "groupes bulbes" a contribué, d'une manière intéressante, à résoudre le problème de la mise en valeur des basses chutes avec des groupes dont les puissances s'échelonnent de quelques dizaines de kW à plus de 10 000 kW.

2. Cette technique doit donc naturellement trouver un champ d'application étendu dans l'approvisionnement en énergie des pays en voie de développement.

3. Dans un groupe bulbe, la roue de turbine et l'alternateur sont calés sur le même arbre, et l'alternateur se trouve à l'intérieur d'une carcasse métallique étanche avec laquelle il fait corps. Cette carcasse a la forme d'un bulbe et se trouve entièrement immergée dans la veine liquide qui alimente la turbine.

I - MICROCENTRALES

4. En France, il existe sur les cours d'eau de plaines d'importance secondaire un très grand nombre de petites chutes. Les microcentrales sont, par définition, les petites installations adaptées aux conditions techniques et économiques de ces très basses chutes. Elles couvrent une gamme de chutes comprises entre 1,50 m et 5 m et une gamme de puissances comprises entre 50 et quelques centaines de kW.

5. Pour que ces équipements soient économiquement viables, ils doivent répondre à un certain nombre d'impératifs :

- Réduction, au strict minimum, des travaux de génie civil : il faut pouvoir profiter de barrages existants, et n'avoir pour ainsi dire pas de travaux de fondations à exécuter ;
- Réduction du prix des machines : par une conception simple et par la construction en série d'un minimum de types normalisés ;
- Allègement des frais d'exploitation : installation entièrement automatique et non gardiennée ;
- Allègement des charges d'entretien : matériel simple et robuste n'exigeant qu'un entretien courant facile ; le gros entretien se faisant en atelier, après échange standard ;
- Allègement des frais de montage et de manutention : matériel léger convenablement fractionné, permettant un transport facile.

6. Le groupe bulbe permet de répondre à ces différentes conditions ; il est monobloc et comprend en général :

- Une turbine hélice à pales fixes mais orientables à l'arrêt ;
- Un distributeur fixe dont les aubes permettent de maintenir le bulbe à l'intérieur de l'enveloppe extérieure ;
- Une génératrice asynchrone tournant dans l'huile.

7. De nombreuses microcentrales ont été réalisées avec des groupes dits "en pertuis" et "en conduite".

8. Nous préférons à ce type de groupe, le "groupe en siphon" : le monobloc étant placé au voisinage du coude du siphon, se trouve toujours

hors d'eau, et il suffit, pour arrêter le groupe, de faire pénétrer l'air dans le haut du siphon à travers une soupape (fig I).

Microcentrales synchrones

9. Dans le cadre de la recherche d'une solution valable pour réseau autonome de faible puissance, c'est-à-dire utilisable par les pays en voie de développement, l'Electricité de France a étudié et mis au point à Echarcon, sur l'Essonne, un prototype de groupe synchrone avec alternateur à aimants permanents.

10. La puissance utile varie de 50 kW sous 1,50 m de chute à 125 kW sous 3 m de chute ; le débit absorbé est de 5 m³/s sous 2 m de chute.

11. Les problèmes d'exploitation ont été simplifiés au maximum en assouplissant les solutions adoptées pour les types antérieurs.

12. La conception de l'appareillage a été radicalement transformée : on s'est attaché à y supprimer tous les organes mobiles autres que les contacteurs.

13. Pour atteindre cet objectif, on a fait usage des semi-conducteurs, ce qui a permis un accomplissement extraordinaire de l'automatisme et une réduction du poids et de l'encombrement de l'appareillage.

14. Pour utilisation sur réseau autonome de faible puissance, la régulation est assurée par une installation d'absorption, entièrement statique, qui règle automatiquement sa puissance de façon que, additionnée à chaque instant à celle appelée par le réseau, la somme des deux termes soit égale à la puissance fournie par la ou les machines en marche. La fréquence du réseau est maintenue constante ou asservie à telle loi de statisme que l'on désire.

II - GROUPES NORMALISES A 800 kW POUR LES CHUTES DE 10 A 18 m

15. L'idée directrice est de réaliser des ouvrages de génie civil identiques dans leur principe, et d'installer des groupes électrogènes identiques, de façon à tirer le meilleur parti d'une réalisation en série.

a)- Dans le domaine du génie civil, on a recherché un type de barrage léger, facilement adaptable aux conditions de chaque site et facilement réalisable. Le barrage à contreforts est constitué par une partie centrale déversante comportant une dalle supérieure en béton armé se prolongeant à l'amont par un voile en béton armé incliné (fig.II). Ce voile et cette dalle reposent sur des contreforts distants de 6 m. On détermine ainsi un certain nombre de cellules où l'on installe des groupes en nombre convenable, à raison d'un groupe par cellule.

b)- Dans le domaine du matériel électromécanique, on a recherché également la simplification par l'adoption d'un type unique de groupe, le groupe bulbe axial. Chaque cellule comporte une conduite forcée de 1,70 m de diamètre, une vanne papillon et le groupe bulbe amont comprenant :

- Une turbine hélice à distributeur fixe et roue de 1,12 m de diamètre à 5 pales fixes, orientables à l'arrêt absorbant 7,5 m³/s sous 13 m.
- Une génératrice asynchrone de 800 kW sous 1 500 V

16. Le Poids total d'un groupe est inférieur à 12 t.

17. La marche de ces groupes est, comme pour le groupe asynchrone des microcentrales, une marche par tout ou rien.

18. La mise en route ou l'arrêt d'un groupe se fait uniquement par

simple ouverture ou fermeture de la vanne papillon.

19. Il est possible que cette conception trouve une certaine généralisation pour des rivières dont le débit moyen est compris entre 5 et 10 m³/s et susceptibles d'un découpage en tronçons de 10 à 18 m de hauteur de chute.

III- GROUPES BULBES INDUSTRIELS-CENTRALE MAREMOTRICE DE LA RANCE

20. La puissance des groupes bulbes industriels est trop importante pour s'accommoder d'un fonctionnement par tout ou rien, d'où la nécessité d'une conception plus affinée que celle des groupes des deux premières catégories dont nous venons de parler.

21. La roue à pales fixes doit céder la place à une roue dont les pales sont orientables en marche. Le distributeur n'est plus fixe et l'orientation de ses aubes est en général conjuguée avec celle des pales de la turbine. Il est précédé en général d'un distributeur fixe utilisé pour la fixation du bulbe à l'intérieur de l'enveloppe.

22. L'alternateur est une machine synchrone dont l'excitation peut être obtenue par les moyens classiques (excitatrice ou redresseur).

23. Enfin, les groupes bulbes industriels se caractérisent par le fait que l'intérieur du bulbe est en général accessible.

24. Le problème des groupes bulbes de grande puissance s'est posé à l'Electricité de France à l'occasion du projet de l'usine marémotrice de la Rance qui nécessita l'étude et la mise au point de groupes pouvant fonctionner en turbine et en pompe dans les deux sens du flux.

25. Après essais sur modèles réduits les prototypes suivants ont été réalisés :

à Argentat

- Un groupe bulbe aval de 14 MW sur la Dordogne, (1958)
- Deux groupes bulbe aval de 5 MW à Gambeyrac, sur la Truyère (1957)
- Un groupe bulbe amont de 8,5 MW à Beaumont-Monteux, sur l'Isère (1959)
- Un groupe bulbe amont de 9 MW à Saint-Malo (1959), fig III

26. Les progrès techniques réalisés au cours de ces expérimentations ont permis de mettre au point le type de groupe définitivement retenu en 1960 pour l'Usine marémotrice de la Rance.

IV - AVANTAGES DES GROUPES BULBES

a)- Turbines

27. Le conduit rectiligne a une influence favorable sur l'alimentation de la roue, ainsi que sur le rendement de l'aspirateur.

28. Avec des conditions équivalentes de protection contre la cavitation, les groupes bulbes à axe horizontal permettent un gain très important sur la profondeur des fouilles.

29. La hauteur du bâtiment-usine est moins grande du fait du plus faible encombrement en hauteur du groupe bulbe. On gagne également sur la longueur du bâtiment-usine, car l'entr'axe des groupes bulbes est bien inférieur à celui des groupes classiques.

30. La figure IV montre la comparaison entre les conceptions verticale et horizontale des groupes de la Rance :

- l'entr'axe se trouve réduit de 20 à 13,3 m
- le groupe bulbe est situé 3 m plus bas, ce qui diminue le risque de cavitation

31. Dans le 1er cas, les manutentions de groupes nécessitaient le déplacement sur la digue d'un portique de grandes dimensions. Dans le 2ème cas, la digue creuse est suffisante pour contenir les 24 groupes de 10 MW, leurs accessoires, les 3 transformateurs de 80 MW, l'appareillage, les auxiliaires, les plages de montage, etc ...

b)- Alternateurs

32. Accouplé directement à la turbine, l'alternateur est caractérisé par :

- un diamètre extérieur beaucoup plus réduit ;
- une puissance polaire, un pas polaire et un entrefer réduits ;
- une valeur optimale de la tension ;
- une ventilation longitudinale ;
- l'évacuation directe des pertes par les parois du bulbe ;
- l'intérêt du fonctionnement dans l'air comprimé.

V - CONCLUSION

33. En résumé, nous avons tout d'abord vu comment la conception du groupe bulbe permet aujourd'hui de tirer économiquement parti de cette importante source d'énergie que constituent les microcentrales.

34. Par ailleurs, par sa standardisation, normalement possible au niveau de 800 kW et 7,5 m³/s, le groupe bulbe constitue la solution la plus intéressante pour l'équipement d'un nombre important de sections de rivières ^{seuls}

35. Enfin, dans le domaine des groupes bulbes industriels, cinq prototypes existent en France.

36. Mais ces expérimentations ont été particulièrement fructueuses ; les études, poursuivies sans relâche depuis 10 ans, ont permis d'améliorer la technique, de telle sorte qu'avec la dernière expérimentation, celle du groupe de Saint-Malo, on peut dire que tous les problèmes ont reçu une solution satisfaisante. C'est d'ailleurs en grande partie, grâce à la réussite de cette dernière expérimentation, qu'a pu être décidée la réalisation de l'Usine marémotrice de la Rance, avec ses 24 groupes bulbes de 10 MW, actuellement en construction (fig V).

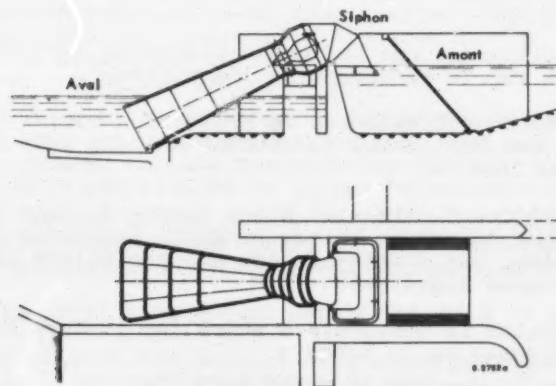


Fig. I - Groupe en siphon

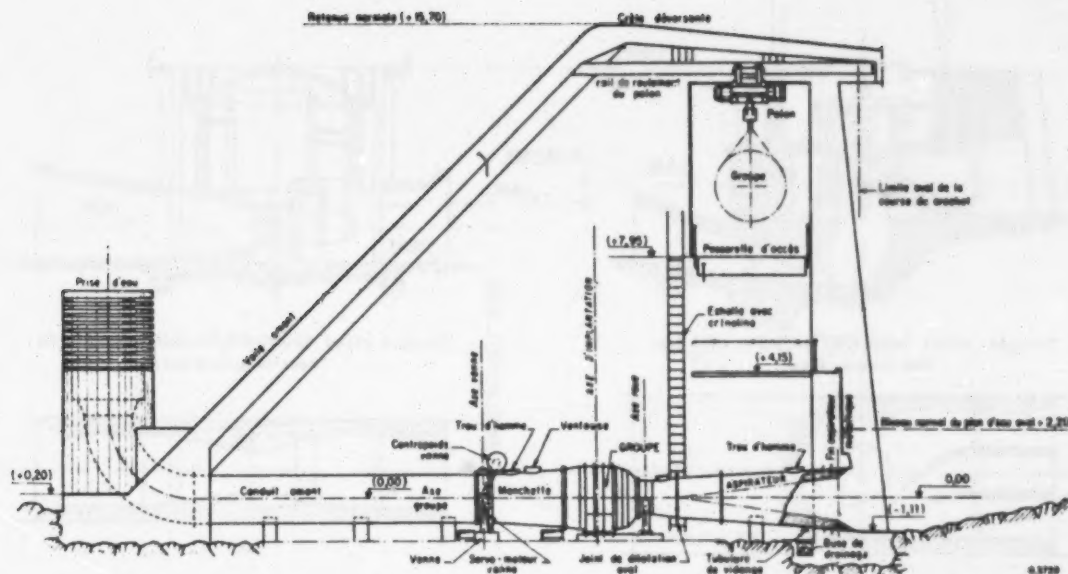


Fig. II - Coupe transversale d'un barrage type "Basse-Maulde"

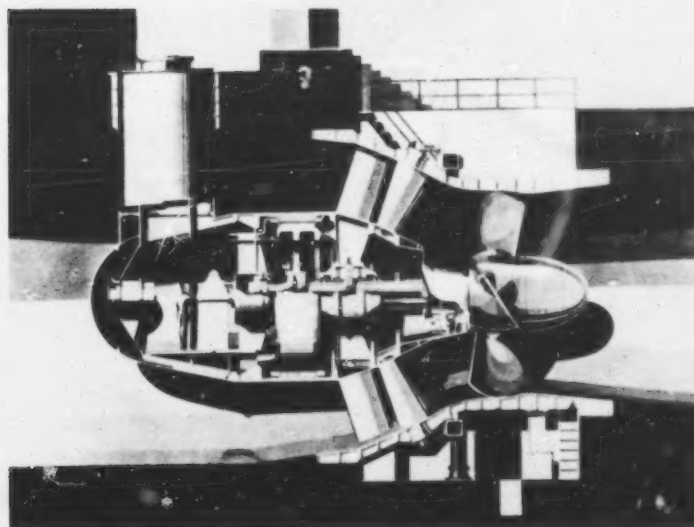


Fig. III - Le groupe bulbe

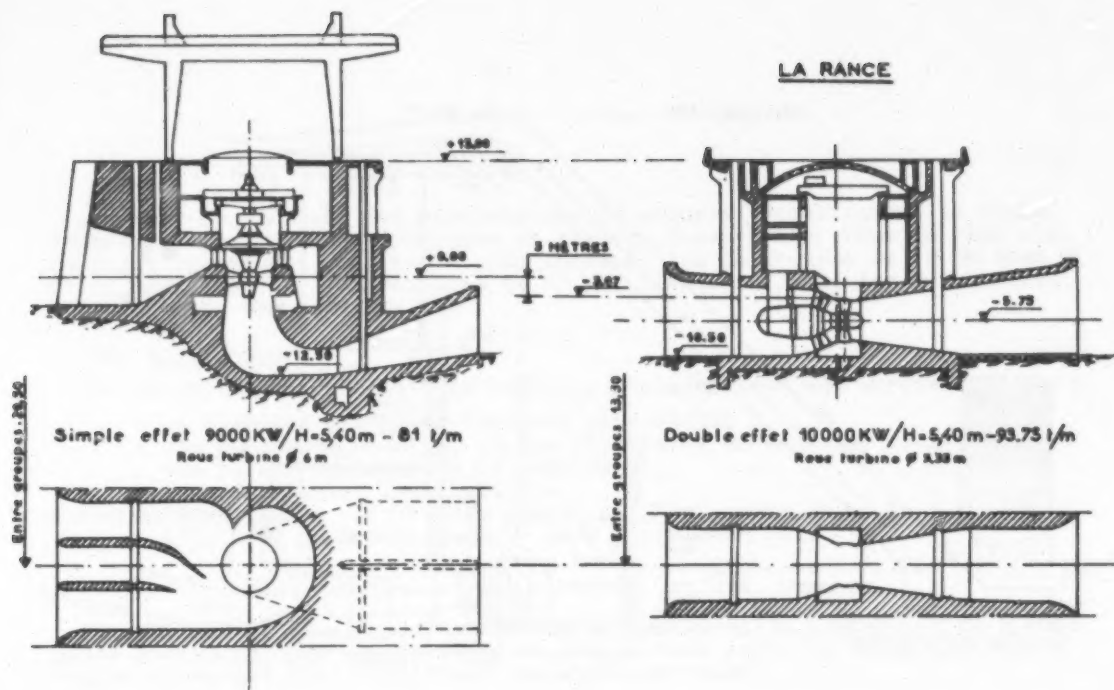


Fig. IV - Comparaison entre les conceptions verticale et horizontale des groupes de la Rance



Fig. V - Centrale Marémotrice de la Rance.
R. D. Pertuis de vannage.